TOMATO PINWORM, KEIFERIA LYCOPERSICELLA (WALSINGHAM): POPULATION DYNAMICS AND ASSESSMENT OF PLANT INJURY IN SOUTHERN FLORIDA

By

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Experiments were conducted in Homestead, Florida, during 1979-1981 to describe tomato plant phenology, tomato pinworm (TPW), *Keiferia lycopersicella* (Walsingham), dispersion patterns, economic damage to tomato and the effects of parasitoids, edgerows, rainfall and cultural practices on TPW population dynamics.

Tomato cv. Flora-Dade phenology was described. Six stages were designated based on the number of leaves, flowers, fruits and physiological plant characteristics. This description can be of use in making pest management decisions.

Based in the relative variation (RV) and sampling costs, sampling units for TPW egg and larval stages were determined. Eggs were generally (51%) found in the upper plant canopy, and larvae (50%) in the lower

plant canopy. Larger sampling units were allocated to the upper and lower plant canopy for eggs and larvae, respectively. An economic injury level was determined to be 1 larva per plant. Yield can be reduced 10-40% when 1-12 larvae are attacking 45 day-old plants. The results indicated a correlation between number of foliar injuries in the lower plant canopy and fruit damage. In southern Florida, higher TPW infestation occurred during March-May, 1980 and March-April, 1981, compared with other months (Jan., Feb.). *Trichogramma pretiosum* Riley caused 33-73% TPW egg mortality during May-July, 1981. TPW larval parasitism fluctuated between 39-42% during 1980-1981. The most abundant larval parasite was *Apanteles* spp., followed by *Sympiesis stigmatipennis* and *Temelucha* spp.

TPW adult dispersion and effects of field edges on TPW dispersion and field colonization were evaluated. Field areas surrounded by edge-rows had higher TPW damage than areas surrounded by pastures.

The use of artificial rainfall demonstrated that when plant foliage was irrigated there was a behavioral change in larval feeding which resulted in 50% reduction of larval injuries compared to injuries on soil-irrigated plants. TPW adult emergence was reduced 86% when high levels of water were applied to pupae in the soil.

The effect of cultural practices on the TPW oversummering population was evaluated. The mean number of injuries per m^2 was 28 times higher in crops planted later (December, 1980) than in crops planted earlier (October-November, 1980). Lower numbers of injuries were found in crops disced and mowed than in abandoned fields.

Parasitoids, cultural practices, and southern Florida climatological patterns can have an impact on TPW population levels.

INTRODUCTION

The tomato, Lycopersicon esculentum Mill., is one of the most popular and important vegetables in the world (Purseglove 1968). Tomato production in the U.S.A. is concentrated in California, Florida, Texas, New York, New Jersey, Michigan and Virginia (Thompson and Kelly 1957). Florida tomato acreage was 31360 ha during 1980-1981. Tomato production is considered to comprise 28.31% of the total vegetable acreage in Florida (Anonymous 1982). The tomato growing areas in Florida are divided into 4 major districts: Palmetto-Ruskin, Pompano Beach-Fort Pierce, Dade County and Immokalee-Naples (Anonymous 1981). Dade County has 18.3% of the total state tomato production and supplies most of the winter (December through February) vegetables for the U.S.A.

The cultivation of fresh market tomatoes demands a high monetary investment from farmers. The cost of producing tomatoes in Dade County during 1980 was $5123.25 per ha, which represents an increase of 1.44 times over the production cost of 1975 (Greene et al. 1980).

Expansion of tomato acreage in Florida resulted in changes of agronomic practices to maximize tomato production (Geraldson 1975). Changes in horticultural practices also established an agro-ecosystem with entomological characteristics common to monocultures. From 1950-1975 insect control in tomatoes was almost exclusively chemical. To help growers avoid problems with insecticides such as insecticide resistance, secondary pest

outbreaks and objectionable pesticide residues, an integrated pest management program was established in Dade County on tomatoes (Pohronezny et al. 1978). This program goal was to develop economically, technically and ecologically sound systems of integrated pest management. This approach had some constraints, however, such as the high crop value which reduces the use of pest management tactics (Bottrell 1979). Moreover, the fruit quality standards for fresh tomatoes cause undue emphasis on chemical control measures in order to prevent contamination of fruit by insects and to prevent cosmetic damage to the fruit (Lange and Bronson 1981).

Accordingly, insect pests in tomatoes can be categorized as direct pests and indirect pests. Direct pests attack the product and directly destroy a significant part of its value. Indirect pests attack plant parts other than the saleable product but may reduce yield of the product (Ruesink and Kogan 1975). Among direct pests of tomato in Florida are the corn earworm, Heliothis zea Boddie, the southern armyworm, Spodoptera eridania (Cramer), and the tomato pinworm, Keiferia lycopersicella (Walsingham). Indirect pests are the serpentine leafminer complex, Liriomyza spp, the tobacco hornworm, Manduca sexta (Joh.), and the granulate cutworm, Feltia subterranea (Fab) (Poe 1972).

The tomato pinworm (TPW) can be either a direct or indirect pest of tomatoes. The larva of this insect feeds in the mesophyll of the leaves causing a serpentine-type mine during the first 2 larval instars. In the latter instars the larvae can cause a blotch-type mine or they tie leaflets together. The larvae also bore into fruit, providing an entrance for plant pathogens which cause major damage to fruit.

The importance of the TPW as one of the most serious pests that affect tomato production in semitropical areas of Florida has been documented by Poe (1974a) and Wolfenbarger et al. (1975). Tomato pinworm incidence was noted in Florida as early as 1932 (Watson and Thompson 1932) with serious outbreaks occurring during 1942, and from 1970 through 1973. Several factors have been mentioned by Poe et al. (1975) as causing these outbreaks, i.e., type of insecticide used, change of tomato production practices, and harmful effect of pesticides on natural enemies. Other factors such as weather have been overlooked. Current practices for TPW control in Florida have been almost exclusively chemical (Waddill 1975), although emphasis has also been given to breeding tomatoes for TPW-resistance (Schuster 1977a) and less to TPW biological control (V.H. Waddill, personal communication). The effects of several factors, e.g., rainfall and cultural practices, that influence the life system of the TPW are still not understood.

To develop effective integrated pest management for tomato, the interrelationships among the crop (plant physiology, phenology), pests (arthropods, weeds, pathogens) and environment (climate, natural enemies, horticultural practices) must be carefully studied. It is necessary to understand TPW ecology and basic biology by studying the role of several factors that cause seasonal and annual changes in pest populations. The ability to assess the presence and abundance of the pest by accurate sampling techniques would permit a reliable study of TPW potential for inflicting economic damage. By evaluating the role of extrinsic factors, e.g., weather, natural enemies and agronomic practices, it may be possible to reduce the TPW problem.

This study was initiated to answer these and related questions. The specific objectives of research were:

1) to describe different stages of development of the tomato plant.

2) to evaluate techniques for tomato pinworm damage assessment.

3) to discuss sampling techniques for tomato pinworm immature stages under southern Florida conditions and to describe TPW spatial distribution.

4) to evaluate the importance and population dynamics of TPW natural enemies.

5) to evaluate the effect of hedges and edgerows on TPW dispersion and field colonization.

6) to determine a way to assess yield losses in ground tomatoes due to TPW.

7) to determine the influence of rainfall on TPW population.

8) to study post-harvest field managment practices that influence TPW survival.

Therefore, the first chapter is a general literature review of studies on *K. lycopersicella* and addresses the effects of biotic and abiotic factors on the population dynamics of this insect. The second chapter is a study of tomato plant phenology and also covers the evaluation of foliar damage assessment techniques. In chapters III and IV, I address sampling techniques and dispersion patterns of tomato pinworm eggs and larvae. The fifth chapter deals with the effect of tomato pinworm infestation on upper and lower parts of the plant. In the same chapter I state the relationship between TPW population index and yield losses. In chapter six I address the distribution of male moths and larval stages in tomato fields, and the effect of edgerows in such distribution. In chapter VII, I deal with the abundance of egg and larval natural enemies of the tomato pinworm.

The interaction of rainfall and TPW is presented in chapter VIII. Finally, I evaluated the data regarding horticultural practices and the relationship between changes of tomato agroecosystem and oversummering populations of tomato pinworm (chapter IX).

CHAPTER I
LITERATURE REVIEW

Family Gelechiidae

The family Gelechiidae is one of the largest of the microlepidoptera (about 580 North American species). Larvae vary in habits. Some are leafminers, a few form leaf galls, many roll or tie leaves, and one species, Sitotroga cerealella Olivier, is an important pest of stored grains (Borror et al. 1976). Studies on crop pests in this family have been concentrated on pests of high economic importance, such as the pink bollworm (Pectinophora gossypiella Saunders), the potato tuberworm (Phthorimaea operculella Zeller), the angoumois grain moth (S. cerealella), and Keiferia lycopersicella Walsingham, the tomato pinworm.

The pink bollworm and the potato tuberworm are generally considered good colonizers with highly mobile behavior within and between fields (Stern 1979, Van Steenwick et al. 1978); however, many experts considered these moths weak fliers which move great distances by being carried passively by air currents (Kaae et al. 1977). They are capable of having several generations per year, with the last generation showing a strong dispersal tendency (Kaae et al. 1977). The potato tuberworm is perhaps the most closely related to the tomato pinworm in patterns of behavior and plant selection (Hofmaster 1949). Several authors (Shelton and Wyman 1979, Meisner et al. 1974, Traynier 1975) have studied factors

influencing oviposition of potato tuberworm and the relationship between populations of the pest and the host plant. Their studies were used as a base in this research to compare with *K. lycopersicella* population dynamics.

Studies on *Keiferia lycopersicella* (Walsingham)

The tomato pinworm (TPW), *K. lycopersicella* (Wals), is frequently confused with other species (Povolny 1977), particularly with *Scrobipalpula absoluta* (Meyr.) and *Phthorimaea operculella* (Zell.) (Doreste and Nieves 1968), since they are also considered pests of potato and tomato (Povolny 1973). *K. lycopersicella* and *S. absoluta* are apparently isolated from each other geographically and ecologically. *K. lycopersicella* apparently avoids the cordillerian territory of the northern and southern part of South America (Garcia et al. 1974, Mallea et al. 1972, Quiroz 1976). The range of *K. lycopersicella* is in the eastern part of the American continent and penetrates into Central America, Mexico (Povolny 1973) and the U.S.A. (Elmore and Howland 1943). *Phthorimaea operculella* has been reported on tomatoes in Venezuela, (Doreste and Nieves 1968), Bermuda (Grooves 1974), and Egypt (Abdel-Salam et al. 1971).

In the U.S.A. *K. lycopersicella* is considered a key pest of tomatoes in western California (Oatman 1970), Texas, Florida, Pennsylvania and Hawaii (Swesey 1928, Thomas 1933). The tomato pinworm was first recognized as a pest of tomatoes by Morrill (1925), and was later reported by Elmore (1937) and Thomas (1933). In Florida, the TPW has been primarily studied by Watson and Thompson (1932), Swank (1937), and recently by Poe (1973). The seasonal history of the TPW was reported by Elmore

and Howland (1943) in California where it appears first during March and April after overwintering in the pupal stage at or near the surface of the soil. Later studies of the seasonal occurrence of TPW in California showed that larval populations increased abruptly in September and October (Oatman et al. 1979) and in April-June (Oatman 1970). Batiste et al. (1970b) reported that there is no evidence for diapause in this insect. Destruction of the tomato plants shortly after harvest may prevent the insect from surviving the winter and infesting the crop during the following season. Poe (1974a) reported that on the west coast of Florida, severely infested fields occurred in the spring crop (February-May) with less damage on plants during the autumn. Early infestations in greenhouses also lead to heavy losses in the field.

Host Plants of *Keiferia lycopersicella*

Elmore and Howland (1943) reported that tomato and potato are preferred hosts of TPW. Several solanaceous plants, e.g. eggplant [*Solanum melongena* (L)] and nightshade (*Solanum nigrum* L.), also are known hosts for the TPW (Batiste et al. 1970b, Elmore and Howland 1943, Swank 1937, Thomas 1933). Batiste and Olson (1973) demonstrated that *K. lycopersicella* preferred tomato for oviposition over 12 other solanaceous plant species. TPW could be reared on *Solanum melongena* L., *S. dulcamara* L., *S. nigrum*, and *S. elaegnifolium* Cav. but not on *S. nodiflorum* Jacq., *S. douglasi* Dunal, *Datura meteloides* A., *D. stramonium* L., *D. ferox* L., *Nicotiana biglovii* (Torr.) and *N. glauca* Grah. The same author suggests that in California, *Solanum melongena*, *S. dulcamara* and *S. elaegnifolium* may play a role in the population dynamics and distribution of TPW.

Life Cycle of *Keiferia lycopersicella*

Accounts of the life history and behavior of *K. lycopersicella* have been reported by Elmore and Howland (1943), Swank (1937), and Poe (1973).

Poe (1973) found that eggs are laid singly or in groups of two or three on the host plant foliage. Elmore and Howland (1943) described the egg as ellipsoid, 0.37 by 0.23 mm, light yellow when first deposited, gradually darkening to a light orange before hatching. Eggs hatch 4-9 days after deposition (Swank 1937) at 20.68°C and after 4-4.5 days at 27-29°C (Elmore and Howland 1943). Weinberg and Lange (1980) determined that eggs hatch in a range of 3.5 $\pm$ 0 days at 35°C and 7.8 $\pm$ 0.2 days at 20°C.

Keiferia lycopersicella has four larval instars (Elmore and Howland 1943, Swank 1937). Head capsule width of the larval instars are 1st instar 0.14-0.157 mm; 2nd instar 0.23-0.28 mm; 3rd instar 0.36-0.39 mm; 4th instar 0.52-0.61 mm (Elmore and Howland 1943). Newly hatched larvae averaged 0.85 mm in length. The head capsule is dark brown and the remainder of the body is a yellowish gray common to many newly hatched lepidopterous larvae. The mature larvae are 5.8-7.9 mm in length and characterized by an ash gray color with dark purple spots (Elmore and Howland 1943). Larvae of *K. lycopersicella* characteristically possess a pale prothoracic shield with conspicuous dark fuscous shading along lateral and posterior margins (Capps 1946). Duration of the leaf mining (1st-2nd instars) stage ranges between 4.7-5.8 days. The leaf folding stage lasts between 5.6-16 days for a range of temperatures of 13-29°C (Elmore and Howland 1943). Weinberg and Lange (1980) found that egg hatching to pupation times range from 8 $\pm$ 0.9 to 18 $\pm$ 1.6 days when reared at 35°C.

The pupae are initially green, later turning to a brown typical of lepidopterous pupae commonly found in the soil (Elmore and Howland, 1943). Before pupation the larvae form a loose pupal cell of sand grains at a depth of 0.25-1.5 inches beneath the soil surface (Poe 1973). Weinberg and Lange (1980) recorded that pupation requires 11.3 $\pm$ 0.5 at 20°C, and 5.1 $\pm$ 0.2 days at 35°C. The length of the pupal stage was 38.7 and 11.4 days at temperatures of 12.65 and 26.4°C (Elmore and Howland 1943). Swank (1936) obtained a range of 7-17 days with an average of 11 days for the pupal stage at 26°C.

Adults are characterized by an alar expanse of 9-12 mm. Labial palpi have a short forrowed brush on the underside of the second joint, a terminal joint somewhat thickened with scales, and are compressed with the extreme tip pointed. The head and thorax are mottled with dark brown. Forewings are elongate ovate, the hind wings have a pointed apex, a strong pencil of hair scales, are dilated at tip of costa in females, and dilated from base of costa in the males; the abdomen is dark fuscous above with basal joints slightly ochreous, the underside is light ochreous sprinkled with dark fuscous spots. Adult longevity is 7 days (24 $\pm$ 2°C) when they are fed on water and 8.5 days at 24° $\pm$ 2°C when fed a 10% honey solution. At temperatures of 10 and 13°C the respective longevities were 20.5 and 22.8 days (Elmore and Howland 1943).

Insect Behavior

Elmore and Howland (1943) reported that copulation occurs within 24 to 48 hrs after moth emergence, and McLaughlin et al. (1979) stated that

sexual activity such as female calling was greatest during the 1st hr of darkness. Very little copulation occurred after the 3rd hr. Males ran or walked in their approach to calling females. Approach was generally from behind or at ca. 90^{o} to the female and was accompanied by rapid wing fanning. The copulatory strikes of the males were made laterally beside the females. Moths remained in copula from 30 min to 2 hr.

Elmore and Howland (1943) and Poe (1973) described the behavior of larval stages of K. lycopersicella. Newly eclosed larvae disperse briefly from the hatched egg before entering the leaf. First instar larvae spin a tent of silk over themselves and tunnel into the leaf. Further feeding results in a blotch-like mine. The 3rd and 4th larval instars feed from within tied leaves, folded portions of a leaf, or they may enter stems or fruits. The 3rd instar appears to be the most mobile and several types of behavior may occur (Poe 1973). This stage larvae can draw 2 leaves together, may tunnel into stems or fruits at the calyx, but usually the larvae form leaf folds on the upper leaf surface. The four instars can cause injury to 3-6 leaves during development (Poe 1973).

Elmore and Howland (1943) demonstrated that larvae that have mined calyx lobes and nearby tissues enter the fruit instead of folding leaves. Usually, the larvae enter the fruit beneath the calyx lobes or fruit stems, but in heavily infested fields about 50% of the injured fruit may be damaged in other places as well. The damaged areas caused by shallow feeding just beneath the skin of the fruit appear as blotches. Larvae that enter the fruit penetrate to a depth ranging from 0.9-1.9 cm.

Differences in the phenology of larval injuries were studied by Batiste et al. (1970), who found that mines of the early stage larvae

superficially resembled the serpentine type mines produced by dipterous leafminers of the genus Liriomyza. The mines could be distinguished easily, because the dipterous leafminer leaves a trail of frass within the mine, whereas the TPW larvae deposits nearly all the frass in a single mass at the tunnel entrance.

Tomato Plant Resistance to TPW

Breeding for resistance work with tomatoes has largely been concerned with pathogens, but currently there is a renewed emphasis on insect resistance as part of integrated pest management (Lange and Bronson 1981). Resistance to many tomato insects does occur and includes resistance to the fruitworm, *Heliothis zea* (Cosenza and Green 1979); leafminers, *Liriomyza* spp. (Schuster et al. 1979); tomato pinworm, *K. lycopersicella* (Schuster 1977a); hornworms, *Manduca* spp (Kennedy and Henderson 1978), Colorado potato beetle, *Leptinotarsa decemlineata* Say (Schalk and Stoner 1976; potato aphid, *Macrosiphum euphorbiae* (Thomas); flea beetles; white flies (Aleyrodidae); spider mites (Acarina) and many others (Lange and Bronson 1981). The mode of resistance in tomato is complex and may involve many factors including antibiosis, preference, phenological development (such as flowering time, time of fruiting, etc.), morphological characteristics, presence or absence of foliage pigments, foliage volatiles, and physiological incompatibility.

Resistance to the tomato pinworm has been studied by Schuster (1977a), Schuster et al. (1979), and Kennedy and Yamamoto (1979). Schuster (1977a) found that accessions of *Lycopersicon sculentum* Mill x *L. pimpinellifolium* were more susceptible, while those of *L. peruvianum* (L) Mill, *L.*

peruvianum var. humifusum Mill., L. esculentum x L. peruvianum, L. cheesmani f. minor (Hook F) Mull., and L. glandulosum Mull., were less susceptible than the commercial cultivar 'Walter' (L. esculentum Mill.). Selections of L. hirsutum Humb and L. hirsutum f. glabratum Mull. were more resistant and had 25-50% and 50-75% less damage respectively than 'Walter'. In laboratory studies the same author found that mine lengths after 2 days were significantly shorter for PI numbers 129157 (L. hirsutum f glabratum) and 298933 (L. peruvianum). Schuster et al. (1979) stated that levels of resistance to tomato pinworm and vegetable leafminer appeared to be intermediate and the varieties PI 12930 and PI 1404403 of L. esculentum were found moderately resistant to both insects. Kennedy and Yamamoto (1979) found an extractable toxic factor in the foliage of L. hirsutum f. glabratum affecting Manduca sexta, H. zea, K. lycopersicella, Aphis craccivora, A. gossypii, and Myzus persicae. Schuster (1977b) reported that tomato varieties 'Pennorange E 160 A' and 'Pearson' had less fruit damage by K. lycopersicella and armyworms, primarily Spodoptera eridania (Cramer), than did the 'Walter' variety.

Chemical Control of TPW

Chemicals are widely used to control tomato pests. The need for insecticides varies from year to year and from one area to another (Lange and Bronson 1981). Chemical control of TPW was obtained in 1943 by Elmore and Howland (1943) who recommended synthetic cryolite and talc dust (50% sodium fluoaminate). In California, several insecticides were evaluated by Middlekauff et al. (1963) and reevaluated by Batiste et al. (1970a). The latter authors reported little or no control of larvae by

insecticides applied as soil treatments under greenhouse conditions. These same authors stated that methyl parathion was the most effective material in greenhouses, and also recommended parathion, methidathion, phosphamidon, mexacarbamate and methamidophos. Spray deposits of parathion were found by the same authors to be significantly less effective against eggs or early stage larva than was toxaphene-DDT.

Poe and Everett (1974) presented results of experiments to control TPW in 2 locations in Florida. They reported that granular insecticides in general did not perform as well as most spray materials for reduction of the TPW mines and larvae in tomato transplants. They recommended acephate, diazinon, endosulfan, and methomyl to keep seedlings nearly mine free. Chlordimeform was considered phytotoxic to seedlings but when sprayed alone or combined with *Bacillus thuringiensis* Berliner on older plants gave good control of TPW larvae without plant toxicity. Poe and Everett (1974) recommended highly residual insecticides to maintain a crop free of damaged fruit.

Waddill (1980) reported that certain insecticides used on demand for tomato pinworm in Homestead, Florida, significantly reduced TPW damage below that in the untreated check. Permethrin + *Bacillus thuringiensis* were applied least often and were among the best treatments. The author also showed that when used on demand a low rate (0.225 lbs ai) of methomyl resulted in significantly more damage than the same rate plus 0.5 lbs *Bacillus thuringiensis*.

Schuster (1977b) reported that when measured by the number of damaged fruit, the degree of control of the TPW and southern armyworm with *Bacillus thuringiensis* WP and chlordimeform was significantly dependent on the tomato cultivar. The contact toxicity of 4 synthetic

pyrethroids and methomyl to some adult parasites of tomato pests indicated that fenvalerate was generally the least toxic to parasites compared to permethrin, burethrin, and NRD1C49 (±)-d-cyano-m phenoxybenzyl (±) cis, trans-3-(2,2 dichlorovinyl)-2-dimethyl-cyclo-propanecarboxylate) as well as methomyl (Waddill 1980). Fenvalerate was judged the most promising candidate for use in a pest management program in tomatoes for integrated control of the TPW and the vegetable leafminer. Lindquist (1975) obtained the best control of TPW with synergized pyrethrins (MGK pyrethrins) and endosulfan.

Emergence of K. lycopersicella and Apanteles spp from pupae and soil treated with insect growth regulators (IGR's) resulted in 23% suppression of pinworm adult emergence when applied directly to the TPW pupae but was ineffective when applied to the soil. The IGR's caused a reduced emergence of the parasite Apanteles spp from 61% to 0% (Poe 1974b). Prada and Gutierrez (1974) reported some results on microbial insecticide control of Scrobipalpula absoluta, the South American pinworm. Seventy five to eighty percent control of the pest was obtained within 5-100 days after treatment at the rate of 500-200 Neoplectana carpocapsae Weiser nematodes per plant or with Bacillus thuringinesis (150-500 g/ha). Schuster (1982) demonstrated that a mixture of B. thuringiensis and Coax® (454 g + 1.8 kg product/378 lts) when applied to TPW infested tomato seedlings, increased TPW mortality up to 42.2%.

Cultural Practices for TPW Control

According to Lange and Bronson (1981), the mechanization of production of processing tomatoes has not only revolutionized the industry but has altered many control techniques and as a result, a few formerly

major pests have been reduced to a secondary position. Elmore and Howland (1943) considered some cultural practices as undesirable because of their adverse impact on TPW control. These include failure to destroy abandoned plantings, careless disposal of infested culled fruit, and use of infested seedlings. In Florida, Swank (1937) recommended that all material remaining in the field after the crop is harvested be carefully plowed under. He suggested that the carelessly abandoned fields could become a reservoir for infestation of a nearby or succeeding crop. Poe (1973) stated that the best control for TPW is based on several cultural practices: use of non-infested seedlings, destruction of plant debris, use of light traps for adults in small areas, and destruction of plants growing from seeds in compost heaps. Price and Poe (1977) reported that staking and artificial mulching of tomato plants reduced damage caused by *K. lycopersicella* and other pests.

Biological Control of TPW

Employment of biological control measures for insect and mite pests of row crops has been limited, and the poor record probably relates largely to the short-lived row crop environment, which presumably does not permit establishment of the effective host-natural enemy relationships which often characterize more stable environments (van den Bosch et al. 1976). Modern-day biological control techniques have not been fully exploited in tomato under field conditions (Lange and Bronson 1981). They have been widely accepted in European glasshouse tomato production, however. Reports on parasitism of *K. lycopersicella* were made by Elmore and Howland (1943), Swesey (1928), Thomas (1933), Oatman et al. (1979) and Poe (1973) (Table 1).

Table 1. Larval parasites of _Keiferia lycopersicella_ reported from U.S.A. and South America until 1981.

Scientific Name	Family	Place	Reference
Angitia blackburni Cam	Ichneumonidae	Hawaii	Swesey, 1928
Angitia ferrugipeneipes (Ashm.)	Ichneumonidae	Pennsylvania, California	Thomas, 1933
Apanteles epinotiae Vier.	Braconidae	California	Thomas, 1933
Apanteles scutellaris Mues.	Braconidae	California	Elmore and Howland, 1943
Apanteles dignus Mues.	Braconidae	California, Florida	Elmore and Howland (1943), Krombreii et al. (1979)
Apanteles gelechidivorus sp. n.	Braconidae	Colombia,[a] California	March, 1975
Catolaccus aeneoviridis (Gir)	Pteromalidae	California	Elmore and Howland, 1943
Chelonus phthorimae Gahan	Braconidae	California	Elmore and Howland, 1943
Campoplex phthorimaeae (Cus)	Ichneumonidae	California	Elmore and Howland, 1943
Chrysocharis sp Foerster	Eulophidae	California	Elmore and Howland, 1943
Horismenus spp	Eulophidae	Florida	Krombreii et al. 1979
Hormius pallidipes Ashm.	Braconidae	California	Elmore and Howland, 1943
Microbracon junicola (Ashm.)	Braconidae	Pennsylvania, California	Thomas, 1933
Parahormius pallidipes (Ashm.)	Braconidae	California	Oatman et al., 1979
Sympiesis stigmatipennis Girault	Eulophidae	California, Florida	Elmore and Howland, 1943, Krombreii et al., 1979
Spilochalcis hirtifemora Ashmead[b]		Cuba	Castineira and Hernandez, 1980
Tetrastichus sp Holiday	Eulophidae	California	Elmore and Howland, 1943
Zagrammosoma multilineatum (Ashmead)	Eulophidae	Florida	Waddill, 1980
Zatropis sp Crawford	Pteromalidae	California	Elmore and Howland, 1943

[a] Parasite of the South American pinworm _S. absoluta_.

[b] Hyperparasite of _A. dignus_.

Cardona and Oatman (1971) studied the biology of the larval parasitoid *Apanteles dignus* Muesebeck which is a solitary, primary, larval endoparasite of *K. lycopersicella* and found that the total developmental time from egg to adult was ca.18 days at 26.6 ± 1°C and 50 ± 2% RH. Oatman (1970) stated also that the most common parasites at both Indio and Escondido (California) during 1963-64 were *A. scutellaris* (Mues.) and *Parahormius pallidipes* (Ashm.) followed by *Sympiesis stigmatipennis* Girault. The biology of *A. scutellaris* (Mues.) was studied by Djamin (1970). In California, *A. dignus* apparently occurs only along the coast in the southern part of the state. Studies conducted by Oatman et al. (1979) determined that in the south coast there was a range of larval parasitization of 1.6-36.8% during 1972-73. *Apanteles dignus* was the most abundant parasite reared from larvae followed by *S. stigmatipennis* Girault. In Florida, Poe (1974b) reported that 50-70% of tomato pinworm larvae in leaflets collected in the spring, 1973 were parasitized by *Apanteles* spp.

Behavioral Chemicals Used in Monitoring and Control of TPW

Pheromones. Sex pheromones of the adult TPW were obtained by Antonio (1977) from extracts of the whole body of 2-day-old virgin females. A biological assay method was then devised to test males for optimal response to the pheromone under varying conditions. Field evaluation data by the same author indicate that the natural sex pheromones were attractive to male tomato pinworm moths. McLaughlin et al. (1979) found that males were more responsive when bioassayed with dim light from both above and below an olfactometer than when illuminated only from below. The effect of trap design and sex attractant release rates

on TPW catches was studied by Wyman (1979). It was determined that Zoecon 1c® sticky traps were 6 times as effective in capturing TPW males as were Delta® sticky or mineral oil traps. An inverse relationship between attractant release rate (fibres/dispenser) and trapping efficiency was found. *K. lycopersicella* positively responded to a sex attractant of unstated composition dispensed from rubber septa in traps in a tomato field (Wyman 1979).

Deterrents. Beck and Schoonhoven (1980) stated that surface testing of insects touching or piercing with the ovipositor or by biting and probing with the mouth parts is in response to chemical factors that act as incitants. If the stimuli received on initial testing indicate an unacceptable plant, the behavior pattern is interrupted and the insect abandons the plant. Such stimulants are deterrents.

Schuster (1980) reported that survival of TPW was reduced when larvae fed on excised tomato leaflets dipped in solutions of cyhexatin, fentin hydroxyde (triphenytin hydroxide) and guazatine (SN-513); N-n'''-(iminodi-8,1-octanedilyl) bisguanidine. These compounds protected foliage and fruit from insect damage when plants were sprayed in the field.

Tomato Plant Phenology and Measurement of TPW Dispersion and Economic Damage

Little information is available that relates tomato plant phenology to pest management or that concerns dispersion and economic damage of the TPW. Plant phenology related to pest management tactics has been determined already for different crops: alfalfa, cotton, potato, tobacco, soybeans, etc. (Anonymous 1971, Reynolds et al. 1975, Ambrust and Gyrisco 1975, Johnson 1979, Fehr et al. 1971). Tomato plant phenology

as related to pest management has been reported by Alvarez-Rodriguez (1977) and Keularts (1980). Alvarez-Rodriguez (1977) evaluated pest (pathogens and insects) damage as it is related to tomato life table analysis and determined strategies for tomato production. Keularts (1980) determined the effect of artificial defoliation in plants 30-100 days old. These studies should have been complemented by a phenological description of the plant at different plant stages.

Studies of measurement and description of dispersion of TPW populations must involve a sampling program in which biological, statistical and economical aspects of the program are evaluated (Southwood 1978). This information is expected to result in 1) biological interpretation of statistical parameters and 2) the use of this knowledge for measuring of TPW control and for establishing a reliable scouting program. Sampling designs for tomato pinworm larval stages have been studied by Wolfenbarger et al. (1975) and Wellik et al. (1979). Wolfenbarger et al. (1975) developed a sequential sampling program based on the detection of larval feeding on the 3 top leaves per plant. Alternatively Wellik et al. (1979) found that lower leaf and large fruit sampling methods were best for detecting the presence of TPW. These opposing results demand more detailed research in order to obtain more accurate TPW density estimates.

The data concerning tomato pinworm damage range from estimations of damage based on pesticide effectiveness (Batiste et al. 1970a, Poe and Everett 1974, Waddill 1975, 1980), damage evaluation based on effectiveness of parasitism of TPW larvae (Oatman 1970) to estimation

of economic injury levels (Wolfenbarger et al. 1975). Poe and Everett (1974) determined the percentage of unmarketable fruit as 6.5 to 4% when the plant was untreated. Waddill (1980) reported that plants without chemical control may lose up to 75% of the fruit. Oatman (1970) determined tomato fruit was infested up to 70% despite 68.9% larval parasitization. Wolfenbarger et al. (1975) reported that an average of 0.3 TPW injuries per 3 top leaves caused 20% injured fruit.

Environmental Factors Affecting TPW Population

Characteristics of Agroecosystems

Agroecosystems vary widely in stability, continuity, complexity and area. The kind of crops, agronomic practices, changes in land use and weather are important elements affecting the degree of stability of an agroecosystem (Stern et al. 1976). Since agroecosystems are characterized by a short life (Loucks 1970), they are more susceptible to pest damage and catastrophic outbreaks. This also occurs because of a lack of diversity in plant species, insect species, and sudden alterations imposed by man such as plowing, mowing and use of insecticides (Luckman and Metcalf 1975, Pimentel 1961a, b, Smith 1970, van Emdem and Williams 1974).

Tomato Agroecosystem

The tomato crop is a typical example of an agroecosystem with early community succession (Price and Waldbauer 1975). In southern Florida 3 closely related tomato varieties are generally grown: MH1, 'Walter' and 'Flora-Dade' (Volin and Bryan 1976). Horticultural practices are characterized by direct-seeding in the field through mulched beds that will aid in maintaining a regular amount of soil moisture, weed control, and fertilization of the crop (Geraldson 1962, Davis et al. 1970, Bryan et al. 1967). In summary, the tomato crop is typical of agricultural systems with high community energetics, small or low community structure, rapid nutrient cycling, selection pressure (r - selected, many small progeny), and quantitative progeny production. Also, the tomato agroecosystem is characterized by having a few major key pests and secondary pests (Lange and Bronson 1981). Most of these pests, e.g., lepidopterous larvae, stinkbugs, dipterous leafminers, whiteflies, leafhoppers, aphids and some species of beetles, are considered as r selected species with rapid development, high maximal rate of increase (rm), early reproduction, small body size, many small offspring and short length of life (Krebs 1978, Pianka 1978).

Biotic and Abiotic Factors Affecting Insect Population Dynamics

Biotic and abiotic factors exercise some influence on the fluctuation in the number of insects in time and space. To reveal both characteristics the inherent property of animals themselves and environmental conditions in their habitats must be studied (Shiyomi 1976). Among the biotic factors, we should consider the habitat effect on insect

distribution. Effects of habitat have been studied by several researchers: Gossard and Jones 1977, Lyons 1964, Brazzell and Martin 1957, Yamamoto et al. 1969, Wolfson 1980, Sparks and Cheatman 1970, Dethier 1959a, Nishijima 1960. They demonstrated the effect of habitat on oviposition and adult and larval dispersal. The effect of sheltered zones on distribution of insects has been demonstrated by Lewis (1979) van Emdem (1965) and Price (1976). They indicated the importance of crop edge effect on colonization and dispersal of arthropods, especially for r selected species, which show a "safety in numbers" strategy for progeny reproduction and survival. Van Emdem (1965) considered that uncultivated land in regard to the insect fauna of a crop has 2 components: 1) Physical: shelter-survival in debris of woodland, 2) Biological: plants of uncultivated land provide alternate food and breeding sites for injurious insects, crop diseases or alternate hosts for predatory and parasitic insects.

In most agricultural environments the principal pests are usually controlled to a greater or lesser extent by natural enemies (Messenger et al. 1976). The efficiency with which such natural enemies suppress pest populations is influenced on the one hand by their own intrinsic properties and limitations and, on the other hand, by environmental factors and conditions occurring in the agroecosystem under consideration (Messenger et al. 1976).

Among the abiotic factors affecting insect populations, weather and climate are commonly accepted by entomologists as dominant influences on the behavior, abundance and distribution of insects (Messenger

1959). Effects of climate on insect populations were studied by Richards 1961, Nicholson 1958, Cloudsley-Thompson 1962, Andrewartha and Birch 1974. Most authors agree that 2 of these factors, temperature and RH possess a high degree of interaction and affect insect activity and survival. As an example Chapman et al. (1960) and Hofmaster (1949) have looked upon the effect of climate on survival of Gelechiidae.

Finally, pest control in an agroecosystem can be aided by proper use of cultural practices. Two basic principles in the cultural control of arthropod pests are 1) manipulation of the environment to make it less favorable to the pest and 2) manipulation to make it more favorable for their natural enemies (Stern et al. 1976). Cultural methods, however, require a thorough knowledge of crop production and the biology and ecology of the pest and its natural enemies in order to integrate the techniques for pest control into proven agronomic procedures for crop production.

CHAPTER II
DESCRIPTION OF TOMATO PLANT PHENOLOGY AND EVALUATION OF TOMATO PINWORM FOLIAR DAMAGE ASSESSMENT

Introduction

Description of tomato plant phenology and evaluation of tomato pinworm larval presence are major aspects of tomato pest management that need to be determined. First, studies on tomato taxonomy, growth and development, effects of fruit on vegetative growth, and relationship between fresh weight and leaf area are well documented (Cooper 1964, Murneek 1924, Hurd et al. 1979, Romshe 1942, Thompson and Kelly 1957, Purseglove 1968). However, tomato crop phenology that divides the growing plant into characteristic periods and shows the relative time in each period needs to be studied. Second, description of TPW damage to the foliage and TPW mine length correlation with plant resistance has been studied by Elmore and Howland (1943), Batiste et al. (1970) and Schuster (1977). Nevertheless, the evaluation of different techniques for TPW foliar injury assessment is necessary to establish a relationship between larval instars and amount of damage.

The objectives of this study were first, to define growth characteristics of tomato plant during a typical southern Florida growing season, second, to describe from a pest management point of view the phenology of tomato, cv. Flora-Dade, and third, to determine constraints and practical use of TPW larval population indices.

Materials and Methods

The Tomato Crop

Tomatoes, cv Flora-Dade, were planted in 1979 (Nov. 3, Dec. 5), 1980 (Jan. 8, Oct. 30, Nov. 25, Dec. 30), and in 1981 (Jan. 30, Feb. 28) at the University of Florida, Agricultural Research and Education Center, in Homestead, Dade County, Florida. After metribuzin was incorporated into the soil at a rate of 0.84 kg ai/ha, beds 45 m long were prepared and fertilized with 7-14-14, at a rate of 2242 kg/ha. Immediately after fumigation, drip tubing for irrigation was placed ca. 15 cm into the soil and the beds were covered with plastic mulch. Tomato seeds were planted with a seed drill 30 cm apart in the rows. One to two weeks after emergence, the seedlings were thinned to one per hill. Plants were protected from pests by application of fenvalerate 2.4 EC (.045 kg ai/ha), maneb and tribasic copper sulfate (0.97 + 5.71 ai kg/ha) at weekly intervals.

Two to five plants were selected at random from each of the 8 plantings, and height, leaf area, number of leaves, suckers, flowers and fruits were recorded every 8-15 days.

Description of Stages of Tomato Plant

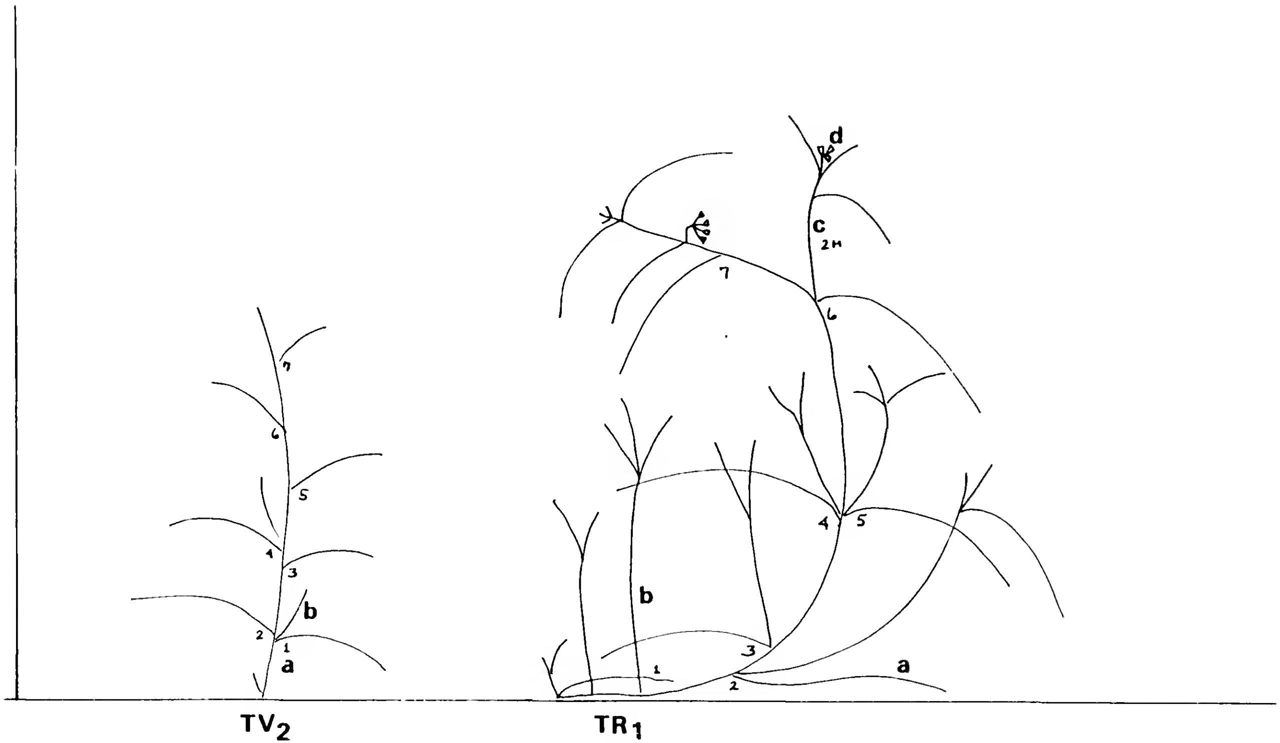
The method used to describe tomato plant phenology was based on the technique of Fehr et al. (1971) for soybeans, *Glycine max* (L). Three developmental stages of tomatoes were defined: vegetative, reproductive, and senescent. Number of leaves, plant height,

time of blooming and fruit formation were averaged from the 8 plantings. Development of the plant was quantified by a nomenclature system, where primary leaves were numbered from the bottom to the top; any secondary growth, e.g., formation of primary laterals (Fig. 1), had the same node number from which it originated, and it was distinguished with a letter(s). The stem that originates from the bifurcation of the main stem was called a secondary main stem (2M); laterals that develop from primary laterals were considered secondary (2S).

Methods of Damage Assessment for TPW Larvae

A set of 3 tomato plants 40-50 days old grown in 20 cm pots was introduced every 2 days into a cage (45 x 45 x 60 cm) for oviposition by moths previously held at 24 $\pm$ 3^{o}C and RH 75 $\pm$ 2%. Plants were subsequently removed, and set aside for larval development. When each set of plants was under attack by 1-4 larval instars, a total of 100 damaged leaves was taken to the laboratory for inspection. A total of 20 individuals was studied per instar. Three methods of measurements were used in separate experiments. First, a portion of leaf area mined by the TPW larvae was separated from the leaf and then measured on a LICOR® model LI3100 area meter. For another set of damaged leaves, leaf weight ingested by the larvae was determined by measuring the differences in weight between the damaged leaflet and the juxtaposed leaflet. Larval instar in both experiments was determined by measurements of the larval head capsule width. Second, a visual classification of damage was made of leaf damage caused by TPW larval instars. A five class

Figure 1. Illustration of tomato cv Flora-Dade growth at 2 stages of development. TV_2=second vegetative stage; TR_1=early reproductive stage; a=primary leaf; b=lateral development.



Tomato Stages of Development

scale of 0-4.5 (Table 2) was devised, based on personal observations and the damage descriptions of Batiste et al. (1970a).

The leaf injury length (cm) was also measured and larval head capsule width recorded. Finally, the presence or absence of TPW larvae in different types of leaf injury was determined. A simple linear regression model was used to examine the relationship between the head capsule width and injury length, and between larval instar and the damage rating scale. The evaluation of the different methods of damage assessment was discussed with regard to the practicality of their use for scouting programs.

Results and Discussion

The Tomato Crop

A summary of leaf area and number of flowers and fruits is shown in Table 3. Tomatoes planted during October, 1980 began to flower 61 days after plant emergence and fruit set occurred at 73 days. Maximum leaf area was reached at 134 days. Tomatoes planted during November, 1980 started blooming at 54 days, and fruit set occurred at 68 days. Maximum leaf area occurred 88-112 days after plant emergence. Tomatoes planted during December, 1980 and January-February, 1981 had a shorter vegetative period, with flowering at 42-62 days and fruiting at 49-62 days. Leaf area reached a maximum at 63-89 days. The total leaf area during these plantings was lower than that produced from fall plantings.

Under southern Florida conditions, average temperature changes drastically from autumn to early spring (Mitchell and Ensign 1928). In this area, the effect of planting date determines growth and tomato

Table 2. Classification of tomato pinworm leaf damage on 'Flora-Dade' tomatoes, based on greenhouse and field observations. Homestead, Florida, 1980.

Degree of Damage	Description
0	No damage
1-1.5	Mining of leaves, ca. 0.50 cm or less in length; mine narrow and elongate; tissue transparent; mine on any part of the leaflet; some leaves attacked by more than 1 larva; small larvae present.
2-2.5	Mining of leaves ca. 0.51-0.68 cm; 1/4 of the mine is necrosed, but changing to a raised area or oblong to ovoid blotch; frass accumulation at the bottom of the injury.
3-3.5	Blotching of leaves; blotch necrosed over 60% of the injury; no holes indicating larval exit; size 1-2 cm; epidermis of the leaf opaque to chlorotic due to larval injury to midvein; construction of silk tent in epidermis.
4-4.5	Leaf folded; fold can occur at any lobe of the leaflet. Necrosis extended to 75-80% of the leaf; extensive frass accumulation on blotch or fold; injury length 2-4 cm.

Table 3. Leaf area and reproductive plant structures in tomatoes, cv Flora-Dade, planted on 5 dates in Homestead, Dade County, Florida during 1980-1981.

Planting Date	Age:Days After Germination	Leaf Area[a] $\bar{x} \pm SE$	No. Flowers $\bar{x} \pm SE$	No. Fruits $\bar{x} \pm SE$	Height (cm)
Oct. 30, 1980	21	1.60±0.32	0	0	15
	35	9.20±1.34	0	0	22
	61	31.20±2.74	7.8±0.46	0	17
	67	22.00±1.06	5.8±1.00	0	49.45
	73	9.80±0.95	14.8±1.77	3.75±0.83	50.00
	79	11.60±1.36	18.6±1.98	7.4 ±0.86	b
	86	23.40±2.67	13.5±1.73	7.4 ±1.00	
	99	27.4 ±2.54	19.4±2.10	11.00±1.50	
	109	20.00±2.40	15.2±1.79	17.20±1.95	
	116	10.6 ±0.54	8.2±1.22	20.2 ±2.08	
	123	23.80±2.72	2.8±0.93	25.80±2.36	
	134	37.20±2.90	0	23.2 ±2.32	
	151	17.80±1.82	0	11.60±1.46	
	159	2.80±0.87	0	0	
	175	3.60±0.32	0	0	

Table 3--continued.

Nov. 25, 1980	32	3.4 ± 0.64	0	0	16
	39	5.6 ± 0.51	0	0	14.5
	45	4.2 ± 0.87	0	0	20.00
	54	8.2 ± 1.43	1.40±0.51	0	20.00
	62	15.0 ± 1.85	8.00±0.69	0	41.00
	68	20.2 ± 2.13	7.4 ±1.23	0.8±0.46	57.6
	74	26.0 ± 2.72	9.6 ±1.37	5.8±0.85	67.2
	81	30.0 ± 2.62	9.0 ±1.55	6.4±1.29	52.0
	88	41.0 ± 3.08	9.6 ±1.44	11.4±1.66	64.0
	94	24.8 ± 2.43	7.2 ±1.11	6.2±0.97	b
	106	29.4 ± 2.54	0	10.0±1.51	
	112	32.8 ± 2.82	0	15.0±1.93	
	132	2.2 ± 0.57	0	0	
	139	2.0 ± 0.10	0	0	
	151	2.4 ± 0.54	0	0	
	156	13.4 ±13.10	0	0	

Table 3--continued.

Dec. 30, 1980	18	1.80±0.41	0	0	7
	24	2.80±0.51	0	0	14.6
	34	2.40±0.57	0	0	21.6
	42	6.00±0.96	0.40±0.42	0	15.0
	49	6.80±0.97	8.40±0.32	1.0±0.02	21.0
	59	16.60±1.91	9.6 ±1.49	7.4±1.01	37.0
	66	8.00±1.28	6.2 ±0.95	5.2±0.46	48.0
	80	12.3 ±1.73	1.2 ±0.57	0.6±0.33	36.0
	87	7.4 ±1.00	0	7.0±1.00	b
	95	9.2 ±1.31	0	0	
	107	4.6 ±1.03	0	0	
	112	9.8 ±1.53	0	0	
	119	3.4 ±0.32	0	0	
	125	8.4 ±0.32	0	0	

Table 3--continued.

Jan. 30, 1981	27	1.3 ±0.54	0	0	9.0
	34	6.6 ±1.23	0	0	4.0
	62	6.6 ±0.91	5.20±0.17	1.20±0.57	15.0
	75	14.6 ±3.15	7.8 ±0.57	6.0 ±0.73	39.0
	81	12.6 ±1.57	2.0 ±0.0	3.6 ±0.81	15.0
	89	23.4 ±2.28	7.8 ±0.46	0	37.0
	100	8.2 ±1.04	0	0	b
	106	5.2 ±1.15	0	0	
	113	6.4 ±0.66	0	0	
	119	7.00±0.73	0	0	
Feb. 28, 1981	25	8.20±1.26	0	0	13.00
	34	1.40±0.32	0	0	13.00
	48	9.40±0.32	3.00±0.00	0	29.00
	55	22.00±2.26	4.20±0.94	3.80±1.11	43[b]
	63	25.00±2.51	5.20±1.03	5.60±1.08	

Table 3--continued.

73	25.00±2.29	8.20±1.13	8.60±1.26	[b]
79	13.00±1.72	4.20±0.87	5.80±1.15	
84	7.40±0.89	0	0	
90	5.60±1.03	0	0	

[a]Leaf area measured in square decimeters.

[b]Plant becomes postrate at this time, changing height patterns.

development. Tomato, cv Flora-Dade, was developed for production of fresh market tomato fruit (Volin and Bryan 1976) during the months of January-March. Consequently, planting before or after the autumn months of October-December resulted in a high reduction of leaf area and yield.

Developmental Stages of Tomato

Vegetative growth of the tomato plant passed through 3 distinct phases (Fig. 2). In the first phase there was a steady increase in leaf area, while in the second phase leaf area was relatively constant. The third phase was characterized by reduction in rate of leaf expansion 130 days after plant emergence. The number of inflorescences rose rapidly to a peak at 70 days and then steadily decreased, whereas fruit reached a peak at 90 days post-planting and then steadily decreased. Flowering and fruit formation were observed at 40 and 50 days, respectively. Three major developmental stages were determined for tomatoes: vegetative, reproductive and senescent (Fig. 3). Each stage was divided into substages. Each substage is explained in detail in Table 4.

The characteristics of tomato plant growth (Fig. 3) demonstrate the relation between leaf area and crop age (days after emergence). The increase in leaf area was observed until half of the second reproductive stage (TR_2). Leaf area is reduced during the third reproductive stage (TR_3) and senescent stage (S_1). I consider that the TR_2 stage can be subdivided into another stage. This will allow a more detailed description of plant stages, as well as shorter time periods for better assessment of pest management.

Figure 2. Influence of time on leaf area (dm^2) expansion, flowering and tomato fruit numbers of cv Flora-Dade grown on 'Rockdale' soil under southern Florida conditions.

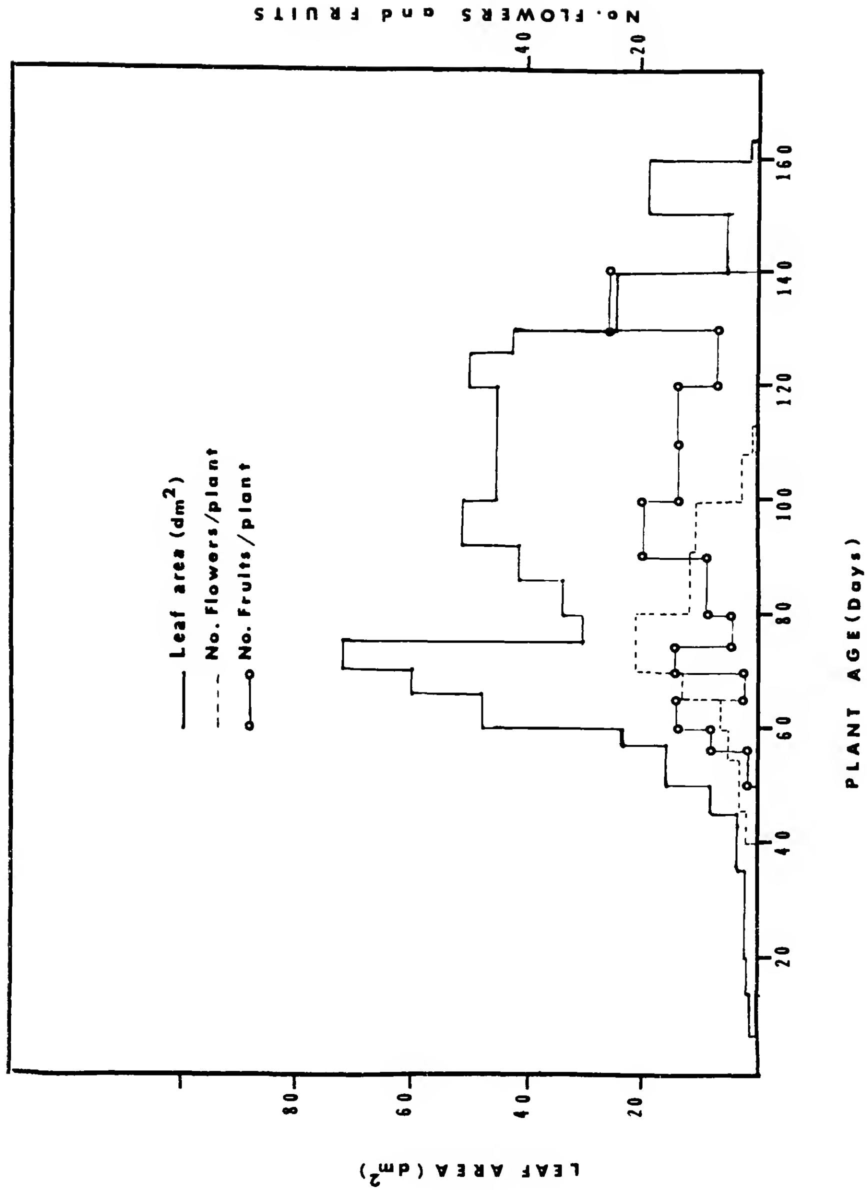

Leaf area (dm^2)
No. Flowers/plant
No. Fruits/plant
No. FLOWERS and FRUITS
40
20
LEAF AREA (dm^2)
80
60
40
20
PLANT AGE (Days)
20
40
60
80
100
120
140
160

Figure 3. Stages of development of tomato. TV_1=early vegetative stage; TV_2=late vegetative stage; TR_1, TR_2, TR_3=reproductive stages; S_1=senescent stages.

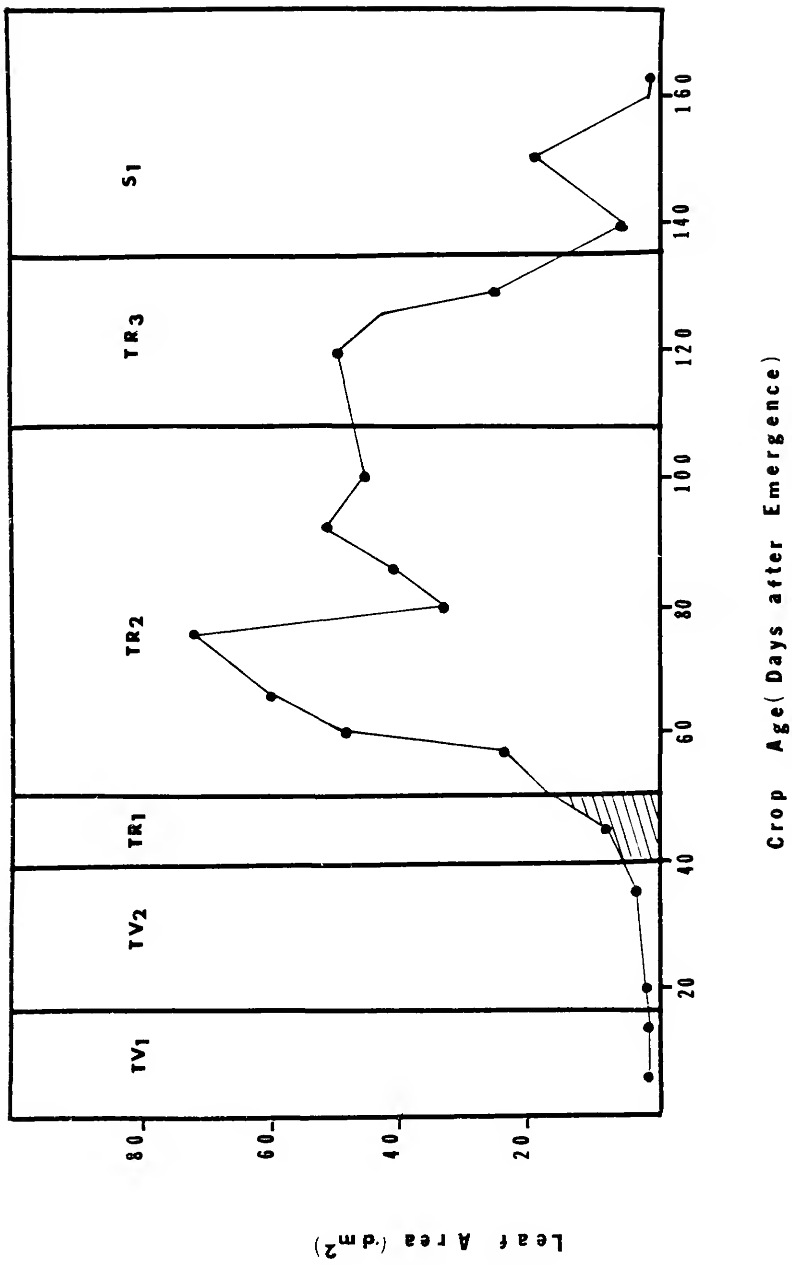

TV1
TV2
TR1
TR2
TR3
S1
20
40
60
80
100
120
140
160
Crop Age(Days after Emergence)
80
60
40
20
Leaf Area (dm2)

Table 4. Stage of development description for tomato cv Flora-Dade. Description is based on the average of observations from tomato plants grown during Fall 1980 through Winter 1981. Homestead, Florida.

Plant Stage	Tomato Plant Description
<u>Vegetative</u>	
TV_1	Plants 1-15 days old. Complete formation of 2-3 primary leaves; loss of cotyledons; plant height ca. 5-7 cm.
TV_2	Plants 16-35 days old; plant erect (12-16 cm); 5-7 leaves, development of laterals; plant with only 1 main stem.
<u>Reproductive</u>	
TR_1	Plant 35-40 days old; development of laterals from nodes 1-5; at leaf 4-5 the stem bifurcates producing another stem as vigorous as the first main stem; production of floral clusters at node 5 and second main stem; height 50 cm.
TR_2	Plants 67-70 days old; fruit set; plant postrated; yellowing of primary leaves.
TR_3	Plant 109-135 days old; 90% fruit ripe; post-harvest maturity; at least 60% of the primary leaves necrosed, development of secondary laterals at nodes 3-5; plant totally postrate; height ca. 32-57 cm.

Table 4--continued.

Senescence	
S_1	Plant 140-200 days old; dead leaves on main stem and second main stem; regrowth of plant from auxillary buds at nodes 1,2 and production of up to 3 floral clusters may occur; possible fruit development.

The principal application of this nomenclature system is to determine the amount of yield reduction produced by damage inflicted at given stages of plant development. As an example, if I use Keularts'(1980) data from his experiment in tomato defoliation, 20% defoliation of lower plant leaves at stages TV_1 through TR_2 did not alter mean yield per plant. However, 20% defoliation of upper plant leaves at TR_2 stage caused yield reduction. The nomenclature system can apply to single plants or entire crops. It would be worthwhile to apply this system to other tomato cultivars.

Methods of Damage Assessment for TPW Larvae

Average leaf area and weight consumed by TPW larvae. The data from this experiment demonstrated the complexity of measuring TPW foliar damage. The average leaf weight (mg) and leaf area (cm^2) consumed by larvae of a determined instar are shown in Table 5. Average leaf area consumed ranged from 0.5 to 1.57 cm^2 for 1st to 4th instar. First and fourth instar larvae consumed 5 and 13.42 mg of leaf, respectively. Variance of leaf weight measurements was large suggesting that many uncontrolled factors influence feeding of individual larvae in the field. Either method might be used for laboratory and greenhouse experiments where the researcher would have more control of the factors influencing variability (e.g., leaflet size, leaf age).

Length of Foliar Injury and Use of Damage Scale

Length of foliar injury and TPW head capsule width were correlated ($r=0.68$; $P=0.001$, $F=39.33$) (Fig. 4). Furthermore, there was

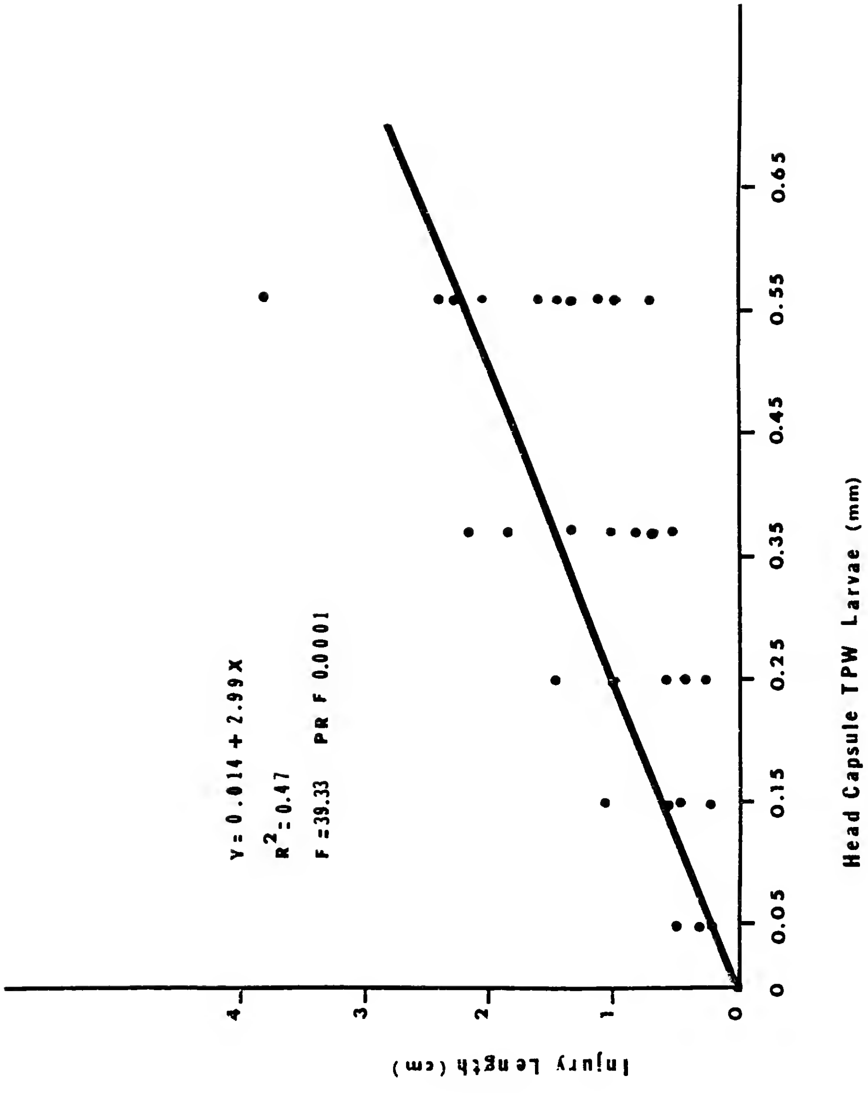
Table 5. Tomato leaf weight and leaf area consumed by different larval instars of *Keiferia lycopersicella* under greenhouse conditions; T 24$\pm$3^{o}C; 75$\pm$2% RH.

	Head Capsule Width[a]			
	0.14 - 0.16	0.23 - 0.30	0.36 - 0.40	0.525 - 0.61
	$\bar{x} \pm SE$	$\bar{x} \pm SE$	$\bar{x} \pm SE$	$\bar{x} \pm SE$
Leaf Weight Consumed (mg)	5.0 $\pm$ 2.86 (11.46, - 1.46)[b]	6.42 $\pm$ 1.31 (10.04, 2.8)	12.7 $\pm$ 2.99 (21.05, 4.42)	13.42 $\pm$ 6.75 (20.17, 6.67)
Leaf Area Consumed (cm^2)	0.5 $\pm$ 0.16 (0.96, 0.14)	1.32 $\pm$ 0.23 (1.82, 0.72)	0.85 $\pm$ 0.11 (0.96, 0.74)	1.57 $\pm$ 1.22 (4.54, 0.35)

[a] Head capsule in mm; each width range corresponds to 1-4 instar.

[b] Confidence limits expressed at 0.05% significance level.

Figure 4. Linear relationship between tomato pinworm (*Keiferia lycopersicella*) larval head capsule width (mm) and foliar injury length, $r^2=0.47$.


Y = 0.014 + 2.99 X
R2 = 0.47
F = 39.33
PR F 0.0001
Injury Length (cm)
0
1
2
3
4
0
0.05
0.15
0.25
0.35
0.45
0.55
0.65
Head Capsule TPW Larvae (mm)

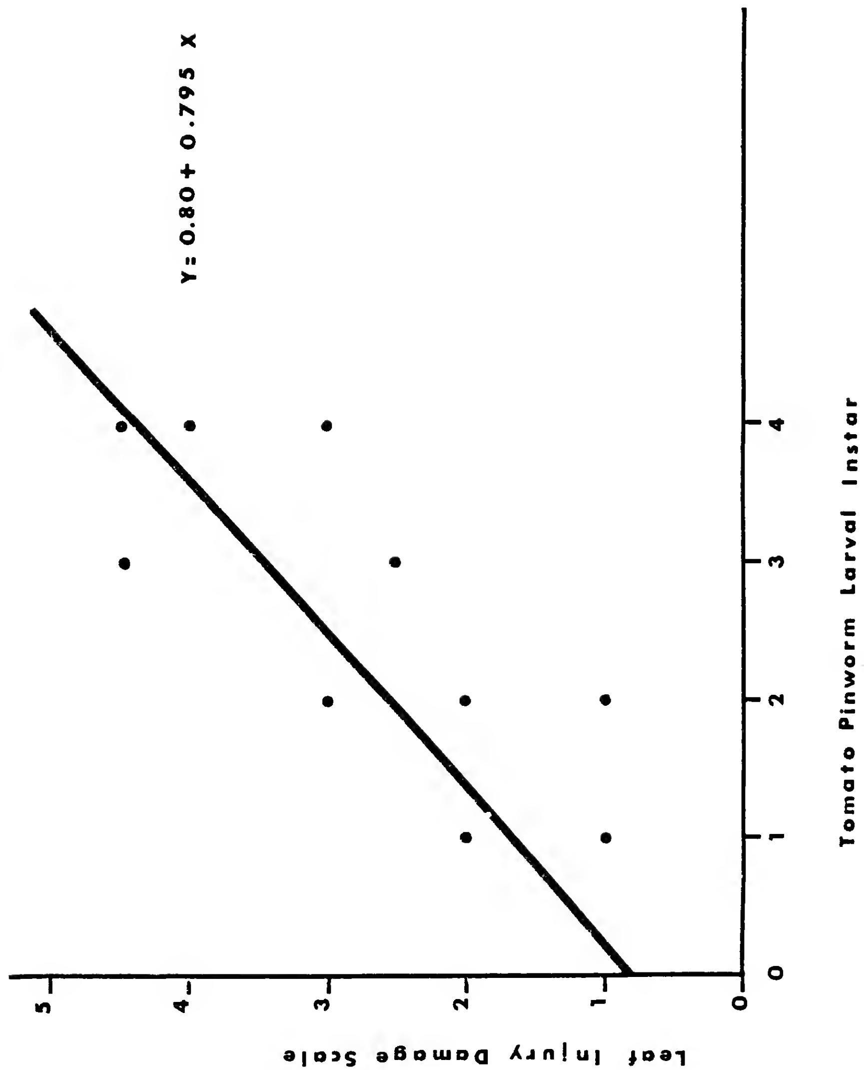
a significant relationship between TPW (Fig. 5) larval instar and the degree of damage observed (r=0.79). Both techniques suggest the possibility of prediction of damage level in the tomato plant at stages TV_1 - TR_1. Such a prediction may be influenced by other factors such as plant stages and larval density.

The use of larval instars to determine injury length has a reduced bias compared to use of TPW damage degree scale. Foliar injury measurement is only advisable for research experiments (e.g., plant resistance, pesticide screening) in which the time frame available to determine the dependent variable is not a constraint. Other aspects to be considered for further study are larval preference for larger or smaller leaflets, as well as presence of different larvae in the same leaflet.

The use of TPW damage scale is perhaps less precise than the technique mentioned above. Damage scale technique may introduce personal error in measurement of larval instar in relation to degree of damage. It is possible, however, to use this technique as an adjunct aid to the population index (number of injuries per plant).

As an example, using the equation $y=0.80 + 0.795x$, where y = the leaf injury damage scale and x = the tomato pinworm larval instar; if the value of x equals 3, the average degree of damage in the plant will be 3.18. This information will help to determine the effect of the insect in economic terms, once the economic threshold is reached for plant stages TV_1 - TR_1. At this point there is no information available for TPW EIL values for plants in these early stages. Therefore, further studies will be necessary to indicate that the presence of a particular larval instar is capable of producing a determined economic damage.

Figure 5. Linear relationship between tomato pinworm (*Keiferia lycopersicella*) larval instars and visual leaf damage scale, $r^2=0.677$.


Y= 0.80+ 0.795 X
Leaf Injury Damage Scale
0
1
2
3
4
5
Tomato Pinworm Larval Instar
0
1
2
3
4

The ratio of percentage of larvae present to percentage of larvae absent (Table 6) in the observed injuries was 4:1 for the folded necrosed injuries, 31:1 for the folded with no necrosis, 1:3 for blotches with necrosed tissue, and 3:1 for transparent blotches. Consequently, the use of necrosed blotches will indicate that ca. 77% TPW larvae will be absent from the observed blotches. If a high number of injuries per plant falls in this category, the probability of not measuring larval presence in each injury is increased. We can deduce that necrosed tissue generally indicates that larvae are already attacking the fruit or other leaves, or have left the canopy to pupate.

In a crop such as tomato where the margin of profit is great, expensive methods of control are usually dictated. The use of a system that will predict the damage level to the plant requires a high level of accuracy. It is suggested that the method described here is advisable for plants during stages TV_1 to RV_1.

Conclusions and General Discussion

Studies of tomato growth in different cropping seasons are useful to determine effect of planting time on plant development. Tomatoes, cv Flora-Dade, planted later in the winter have less (ca. 117 dm^2) leaf area than those planted early in the fall (ca. 253 dm^2 leaf area). Thus, those crops planted in October-November may be able to support more damage than those planted in January-February. The proposed system divides the plant stages into 2 vegetative stages (TV_1 - TV_2), 3 reproductive stages (TR_1, TR_2 and TR_3), and a senescent stage (S_1). The description of the developmental stages of tomato can aid in using pest management tactics. Definition of shorter developmental stages with

Table 6. Percentage of tomato pinworm larval occurrence in foliar injuries with different phenological characteristics.

Damage Description	Percentage of TPW Larval Occurrence	
	Present	Absent
Transparent blotch	72.5	27.5
Necrosed blotch	23.3	76.6
Folded, no necrosed leaf	96.87	3.12
Folded, necrosed leaf	81.25	18.75

with more subdivisions would enhance phenological plant description. This may allow better pest monitoring when plant development is in the TR_2 stage.

Results on leaf weight consumed (mg) and leaf area consumed (cm^2) provided information on increments of those parameters for each larval instar. Standard error and confidence intervals demonstrated a high variability for both methods. Further research is necessary to determine if such variability is caused by larval behavior or by use of different leaflet sizes and leaf area. I consider the leaf weight method promising in such areas as plant resistance and behavioral chemicals (deterrents) evaluation. Damage assessment based on the leaf area mined by TPW is not considered appropriate for monitoring TPW density because of inherent variability in insect behavior and plant morphology.

Injury length has proven useful in evaluating plant resistance (Schuster 1977a). The relationship between larval head capsule and injury length was intermediate (r^2=0.47). The regression equation developed in this study can be used by plant resistance evaluators to determine feeding inhibition at a given instar. This technique has to be carefully used, however, since it is dependent on the type of leaflet consumed. Larvae that attack small leaflets might develop as well as one in a large leaflet but the injury length will be smaller.

Data gathered from the visual damage classification proved to be useful to evaluate damage inflicted by TPW. Since TPW instars have a distinct behavior as leaf blotchers and leaf tiers, it will be easier to develop knowledge in which the average larval instar will determine the damage degree in a plant.

Scouts should use different techniques at the same time if possible. A population index, degree damage scale and a survey determining the real presence of the larvae in the foliage will provide a better estimate than a single technique. More research is needed to evaluate these techniques together. Evaluation should be based on time expended and reliability of the methods. Further study of the relationship between several types of foliar damage and direct damage to the tomato fruit is needed.

CHAPTER III
SPATIAL DISPERSION OF TOMATO PINWORM EGGS ON TOMATOES

Introduction

Tomato pinworm (TPW) is one of the most important pests of tomato _Lycopersicon esculentum_ (Mill.) (Watson and Thompson 1932, Oatman 1970, Poe et al. 1974). Little is known, however, about ovipositional patterns of this pest on tomato plants under field conditions. There is some indication that caged moths under laboratory conditions deposit eggs indiscriminately on all parts of the plant including the upper leaves (Elmore and Howland 1943). Wellik et al. (1979) indicated that lower portions of the plant should be examined in the field for both larvae and eggs of the TPW.

Studies of TPW egg dispersion are necessary because this knowledge affects the sampling program as well as the method of analyzing the data. Furthermore, dispersion patterns can be used to give a measure of population size as well as to describe the factors that may affect the condition of the population. This paper (1) describes the spatial distribution of TPW eggs on field-grown tomato plants under varying levels of TPW infestation, (2) presents an evaluation and discussion of factors affecting this distribution and (3) discusses sampling strategy.

Materials and Methods

Experimental Plots

To test for a possible relationship between oviposition of TPW and different leaf strata of tomato cv Flora-Dade, 8 plantings (Oct. 3, 1979; Dec. 5, 1979; Jan. 8, 1980; Oct. 30, 1980; Nov. 25, 1980; Dec. 30, 1980; Jan. 30, 1981; Feb. 28, 1981) of non-staked tomatoes were evaluated at the Agricultural Research and Education Center, University of Florida, Homestead, Florida. Each planting (ca. 450-947 plants) was direct-seeded in raised beds (3-5) (ca. 45 m long) of Rockdale soil, and mulched with light colored plastic. The seedbed's midlines were 182 cm apart. Plants were spaced 38 cm apart.

Sampling Methods

Sample size was selected by a preliminary random sampling of 50 plants on 2 dates. The method described by Elliott (1979) was adopted. The relative variation $(SE/\bar{x}) \times 100)$ was calculated to compare sampling methods over a variety of sampling units (Hillhouse and Pitre 1974, Ruesink 1980). Ten to twenty plants in each planting were randomly selected on a weekly basis from February 7, 1980, through May, 1980, and from Jan. 27, 1981, through May, 1981. Whole leaves of the plant were first examined to determine differences in oviposition on lower and upper leaf surfaces (Plantings 1-3) and to detect differences in oviposition in different plant strata (Plantings 1-8). A plant was divided into upper half and lower half in the first 3 plantings (1979-80) and divided serially into 6 sections (upper, middle and lower of each of the external and internal canopies) (1980-1981).

External canopy was defined as extending from the periphery to 5-15 cm into the plant interior. The variance was stabilized by fitting the number of eggs obtained to a suitable model (Poisson and negative binomial) and transforming to logarithm (x+1) or x+0.5 (Elliott 1979) depending upon the original frequency distribution of the counts. The mean counts of eggs in upper and lower strata were compared by student's t-test for plantings 1-3. Egg densities in the 6 strata for plantings 4-8 were compared by analysis of variance (ANOVA). Means were grouped by Duncan's Multiple Range Test (P=0.05). When tests indicated significant differences in egg densities between strata of plantings (4-8), optimum sample allocation among strata was determined for each planting date (Cochran 1977).

Population Distribution Related to Leaf Position

To test differences in oviposition of TPW related to the vertical distribution of the leaves with respect to the main axis, 17 randomly sampled plants, each of which were 45 days old, were observed in a commercial field. Leaves were numbered from bottom to top and the number of eggs recorded. Data were analyzed by ANOVA and means were separated by use of Duncan's Multiple Range Test (P=0.05). When t-tests indicated significant differences in egg densities between leaves, optimum sample allocation among leaves was determined (Cochran 1977).

Distances Between Eggs and Effects on Distribution

To determine if TPW egg distribution pattern is influenced by leaflet size and egg density, the frequency of egg deposition on each

leaflet was recorded. Then, distance between eggs on each leaflet was counted on 40 middle leaves collected from plants located in the same field mentioned before. Several authors (Cottam and Curtis 1956) proposed methods to evaluate randomness in spatial distribution of the population by measurement of distances between individuals. In this experiment, distance between eggs was checked by measuring the shortest straight line between nearest neighbors with a metric ruler. Distance accuracy was 0.05-0.25 cm. The frequency of occurrence of each distance was evaluated for egg densities. Also, simple linear regression was applied to determine any relation between egg density and leaflet size.

Oviposition Related to Plant Age

To determine if plant age affects oviposition, the number of eggs on each plant was counted on 60-80 plants ranging in age from 2 to 21 weeks. Plants in this experiment were in the same field as previously described tests (plantings 4-8). Plants were inspected weekly during April and May, when the highest peaks of oviposition occurred. Data were subjected to ANOVA, and means separated by use of Duncan's Multiple Range Test (P=0.05).

Results and Discussion

Selection of Number of Sample Units

The main objective of planning a survey should be to obtain the required information with a minimum amount of labor. To achieve this, it is necessary to select a number of sample units that are in agreement

with the desired degree of precision and cost. This requirement is difficult to meet in practice. First, an acceptable index of precision $(\frac{SE}{\bar{x}}x100)$ is 25% (Barfield 1981). Secondly, the actual cost of sampling tomatoes is 7 dollars per acre (Table 7).

Sample size was selected by a preliminary random sampling of 50 plants in 2 dates (Table 6). Three major criteria were followed to select sample size. First, following the criteria outlined by Elliott (1979), a suitable sample size was selected when the mean value ceased to fluctuate. It is observed (Table 5) that with an increase in sample size from 10 to 25 (at low egg density), the resultant mean $(\bar{x})$ fluctuates around 0.4-1.5 eggs/plant. Also, at higher egg density (2-7 eggs/plant) the number of selected sampling units is 20-25. Second, the use of index of precision $(\frac{SE}{x}x100)$ over different sampling units is a more adequate technique to select sample unit size.

Accordingly, the lower index of precision (Ip) was obtained when the number of samples equals 50. Therefore, the percentage of the standard error of the mean can be 34% if the TPW egg density per plant is low (0.4-1.5 eggs/plant). This percentage is not good enough to make pest management decisions. The index of precision can be 20% if the density is higher (2-7 eggs/plant). Third, the sample number does not reconcile with the actual budget per acre. Cost of sampling eggs is 1.4-77 dollars (Table 5) more expensive than the actual sampling cost per acre.

The number of samples for a fixed level of precision (random sampling) was calculated. A random egg distribution was assumed, $n=(\frac{s}{E\bar{x}})^2$ where, n=number of samples required, s=standard deviation, $\bar{x}$=mean, and E=predetermined standard error (e.g., 0.25). For instance, at

Table 7. Comparison of different sample sizes for tomato pinworm eggs. Homestead, Dade County, Florida, 1980.

Egg Density	No. Plants Sampled	Mean Eggs/Plant	S^2	SE	$(SE/\bar{x})x100$	Cost of Sampling/Acre[a]
Low[b]	5	0.4	0.8	0.4	200	8.4
	10	1.5	14.5	1.18	78	16.8
	15	1.33	9.95	0.814	61	25.2
	20	1.15	7.81	0.624	54	33.6
	25	1.08	8.26	0.574	53	42
	50	0.88	4.59	0.302	34	84
High	5	7	23.5	2.16	31	8.4
	10	3.9	19.78	1.4	36	16.8
	15	3.4	17.66	1.08	31	25.2
	20	2.9	14.62	0.854	29	33.6
	25	2.96	15.29	0.874	29	42
	50	2.16	9.28	0.43	20	84

[a] Cost of sampling was calculated on the basis of \$7.00/man hr for scouting tomatoes. Average time spent per plant was 14.4 min.

[b] Egg density was considered low when mean eggs/plant ranged 0.4-0.88; egg density was considered high when mean eggs/plant ranged 2.16-7.

endemic levels of TPW egg population (0.4-1.33), the number of samples to be taken, being $s=2.79$, $E=0.25$, $\bar{x}=1.15$ will be 94, with a cost of 158 dollars per acre. If the TPW egg population is epidemic (2.16-7), the number of samples to be taken will be 28, being $s=3.82$, $\bar{x}=2.9$ and $E=0.25$. The cost of sampling will be 47 dollars per acre.

Accordingly, under low TPW egg densities, increasing sample precision as the sample size increases is not worth the work required in taking larger samples. Consequently, I selected sample sizes of 10-20 which gave the best practical results per unit of work expended ($16.8-25.2 dollars per acre). It is considered that sampling TPW eggs is not a practical method to make spray decisions.

Statistical Description of TPW Egg Spatial Distribution

The use of statistical methods, e.g., t-tests, analysis of variance, involves several conditions described by Snedecor and Cochran (1967). One of them is that data must follow a normal distribution. The distributions of density measurements on plant samples are summarized for each planting in the Appendix. These statistics (Table 8) support the hypothesis that TPW eggs are clustered on plants. This clustering was more apparent when TPW egg densities on each plant ranged from 0.302-1.3. As mean densities increased, variance also increased except for planting 6. Values of the negative binomial parameter (k) (Elliott 1979) range from 0.451-0.013 for my sampling. Thirty-two percent of the weekly counts for each planting were fitted to the negative binomial distribution (see Appendix). For plantings with higher

Table 8. Mean number of tomato pinworm eggs per plant by planting date for 8 tomato plantings in Homestead, Florida, 1979-1981.

No.	Planting Date	Mean	Variance	Skewness	Kurtosis	CV	k[a]	I[b]
1	Nov. 3, 1979	1.30	5.04	2.96	13.74	172.41	0.451	4.17
2	Dec. 5, 1979	0.736	2.44	2.78	8.18	212.24	0.317	3.05
3	Jan. 8, 1980	0.345	0.97	4.332	23.97	285.73	0.190	2.15
4	Oct. 30, 1980	0.037	0.139	18.28	405.40	993.60	0.013	2.79
5	Nov. 25, 1980	0.135	1.34	16.18	314.24	858.16	0.015	9.06
6	Dec. 30, 1980	0.532	0.315	5.44	33.707	423.38	-1	0.124
7	Jan. 30, 1981	0.221	0.52	4.91	31.04	328.65	0.1633	1.57
8	Feb. 28, 1981	0.302	0.74	4.34	24.35	286.19	0.208	1.75

[a] $k = \dfrac{\bar{x}}{\dfrac{S^2}{\bar{x}} - 1}$

[b] $I = \dfrac{S^2 + (\bar{x})^2}{\bar{x}} - 1$

population densities (average 0.302-1.30), kurtosis and skewness decreased as the mean increased. Skewness values were all positive. This indicates that egg distribution tails off among higher counts. This information in conjunction with the data indicating clumping can aid in sampling design.

Distribution of Eggs on the Upper and Lower Surfaces of Leaves

Statistically significant differences (P=0.01) were found for egg numbers on lower and upper leaf surfaces. Eighty-nine percent of the total eggs found per plant were on the lower surface (Table 9). These results and the results from the greenhouse contrast with those found in caged plants by Elmore and Howland (1943), who detected 45% of all egg deposition on the upper surface of the leaves. Insect preferences for oviposition on the underside might be correlated with differences in pubescence of the 2 leaf surfaces. The average number of trichomes on the underside was 1441 per leaflet as opposed to 469 on the upper surface. This may also indicate preference to avoid egg desiccation, or to avoid higher light intensities during oviposition (Hinton 1981).

Distribution of Eggs on Upper and Lower Halves of the Plant

Statistically significant differences (P=0.05) were found in the number of eggs deposited on the upper half of the plant vs the lower half of the plant for the 3 sample dates in the first planting (Table 10). The upper part of the plant had more eggs on 13 of the 15 sampling dates. There were no significant differences between upper and lower halves

Table 9. Ovipositional preference of tomato pinworm for upper and lower surfaces of tomato leaves from plants grown under greenhouse and field conditions.

Leaf Side	Mean Number of Eggs of TPW	
	Field[a]	Greenhouse Caged Plants[b]
Upper	0.857[c]	0.10[c]
Lower	7.3763	2.77

[a]Mean based on counts from 80 plants.

[b]Mean based on counts from 60 plants.

[c]Numbers were significantly different at P=0.001.

Table 10. Mean number of tomato pinworm eggs in 2 plant strata (upper and lower halves) per plant at different sampling dates. Homestead, Dade County, Florida, 1980.

		Mean Egg Density* of TPW Eggs Per Stratum On Specified Dates												
Planting	Strata	2/7	2/12	2/21	3/7	3/14	3/21	3/27	4/5	4/11	4/18	4/24	5/2	5/10
1	Upper half	0.05**	0.05	0.50[a]	0.35	0.55	0.35	1.45	1.80	2.30[a]	2.70	1.25[a]		
	Lower half	0.50	0.00	0.10[b]	0.20	0.65	0.15	1.25	1.20	1.20[b]	2.55	0.75[b]		
2	Upper half			0.00	0.07	0.07	0.15	1.04[a]	0.18	0.39	0.18	-	0.311	
	Lower half			0.00	0.07	0.07	0.12	0.45[b]	0.12	0.23	0.04	-	0.139	
3	Upper half			0.00	0.00	0.15	0.25[a]	0.15	0.25	1.7[a]	1.15	0.10	1.05[a]	1.1[a]
	Lower half			0.00	0.15	0.00	0.15[b]	0.10	0.30	0.6[b]	0.25	0.00	0.35[b]	0.2[b]

*Data transformed back to the original units after statistical analysis of transformed data.

**Means followed by different letters, in the same planting and date, are significantly different at P=0.05 according to t-test.

in the second planting (Dec., 1979). Analysis of the data from the third planting (Jan., 1980) indicated significant differences in 6 of the 11 sampling dates. The upper half of the plant had more eggs except for 2 dates. In general, when numbers of eggs were higher in the lower strata, this coincided with younger plant age (40-60 days after germination). Numbers of eggs were higher in the upper strata when plants were in reproductive or older age (75-80 days after germination. These data indicated that for 'Flora-Dade' ground tomatoes, ovipositional preferences existed based on the level of the plant. Because of the low economic threshold for TPW in tomatoes, it may be necessary to reduce the sampling unit to detect major differences in internal and external parts of the plant when populations are low. Consequently, smaller sampling units were tested in subsequent experiments.

Distribution of TPW Eggs by Sampling Six Plant Strata

Statistically significant (P=0.05) (Table 11) differences were not detected among the strata for the 4th (Oct., 1980) and 5th (Nov., 1980) plantings possibly due to the relatively low mean egg numbers per plant. However, the highest number of eggs oviposited was obtained in the upper external canopy for planting 4 and in the middle internal canopy for planting 5. There was an increase in eggs for the lower internal canopy in planting 4 during January and February, when nocturnal temperatures were lowest (2°C), and an increase toward the upper external portion of the plants when temperatures were fluctuating between 17-29°C (April-May).

Table 11. Mean number of tomato pinworm eggs per plant in 6 strata: upper, middle and lower external; upper, middle and lower internal canopy of the tomato plant. Homestead, Florida, 1981.

		Mean Egg Density* of TPW Eggs per Stratum on Specified Dates												
Planting	Strata	1/27	2/4	2/10	2/17	2/25	3/18	4/1	4/8	4/16	4/24	5/1	5/8	5/14
4	Upper external	0.00[a]**	0.05	0.00	0.00	0.05	0.15	0.00	0.30	0.20	0.20	1.3		
	Middle external	0.05	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.10	0.00		
	Lower external	0.00	0.05	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
	Upper internal	0.00	0.00	0.00	0.00	0.00	0.00 .	0.00	0.00	0.00	0.00	0.00		
	Middle internal	0.00	0.10	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00		
	Lower internal	0.05	0.40	0.05	0.00	0.40	0.00	0.05	0.00	0.00	0.00	0.00		
5	Upper external						0.00	0.00	0.60	0.05	0.40	0.10	0.60	0.10
	Middle external						0.00	0.00	0.10	0.10	0.00	0.00	0.10	0.10
	Lower external						0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10
	Upper internal						0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00
	Middle internal						0.00	0.05	0.40	0.00	2.05	0.00	0.00	0.00
	Lower internal						0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00

Table 11--continued.

6	Upper external	0.00	0.70	0.30	0.25	0.10	0.30^{a}	0.90^{a}	0.20
	Middle external	0.00	0.40	0.20	0.15	0.20	0.00	0.10^{b}	0.40
	Lower external	0.00	0.20	0.30	0.00	0.00	0.15^{ab}	0.00^{b}	0.00
	Upper internal	0.00	0.10	0.10	0.25	0.00	0.00^{b}	0.00^{b}	0.00
	Middle internal	0.00	0.30	0.30	0.10	0.00	0.00^{b}	0.00	0.00
	Lower internal	0.00	0.20	0.00	0.00	0.00	0.05	0.00	0.00
7	Upper external			0.70	0.60^{ab}	1.00^{a}	0.75^{a}	0.50^{a}	0.30^{a}
	Middle external			0.00	0.80^{a}	0.45^{b}	0.55^{a}	0.40^{ab}	0.10^{b}
	Lower external			0.40	0.10^{bc}	0.05^{b}	0.05^{b}	0.35^{b}	0.00
	Upper internal			0.00	0.00	0.05^{b}	0.00^{b}	0.00^{b}	0.00
	Middle internal			0.40	0.00	0.30^{b}	0.20^{b}	0.00	0.00
	Lower internal			0.10	0.00	0.05^{b}	0.00	0.00	0.00

Table 11--continued.

8	Upper external	0.10	0.40	0.55	1.20[ab]	0.55[a]	1.80[a]
	Middle external	0.30	0.20	0.25	0.85[b]	0.10[ab]	0.25[ab]
	Lower external	0.00	0.40	0.05	0.40[b]	0.25[ab]	0.20[ab]
	Upper internal	0.00	0.00	0.00	0.10[b]	0.25[ab]	0.10[b]
	Middle internal	0.00	0.00	0.25	0.15[b]	0.25[ab]	0.20[ab]
	Lower internal	0.00	0.00	0.00	0.15[b]	0.00	0.10[b]

*Data retransformed to the original units after statistical analysis.

**Numbers followed by different letters, in the same date and planting are significantly different at P=0.05 according to Duncan's Multiple Range Test.

Perhaps moths protect themselves from the cold temperatures by staying close to the ground in the lower canopy. Despite these assumptions, when number of eggs found per stratum was regressed (Table 12) against temperature, there was no evidence of a relationship between the two variables. Significant differences in numbers of eggs per stratum were detected for the 6 (Dec., 1980), 7 (Jan., 1981) and 8 (Feb., 1981) plantings. There was no significant variation among the six strata during juvenile plant stages. Most of the significant differences were observed (Fig. 6) during the mature stages (TR) of the plant. Concentrations of eggs in the upper external strata varied slightly among plantings. In plantings 4 and 5, eggs generally occurred on the top and middle external canopy during the last weeks of sampling (April and May), and on all strata during the first weeks (juvenile stages) in March and April. When mean numbers of eggs in the external and internal canopy were added to reduce the strata to 3 (upper, middle and lower), no statistical differences were observed despite the stratum reduction. This agrees with the results expressed when 2 strata (upper and lower) were sampled, indicating that differences in oviposition tend to be masked if the units are widened. In general, the upper external stratum had the highest number of eggs, followed by the middle external and internal strata, during most of the sampling dates. At plantings 6 to 8, the TPW eggs occurred in greatest abundance on the upper and middle external strata during all growth stages. More eggs (44-68%) were deposited within the upper external canopy of the plant than in any other stratum (Table 13). Four to twenty eight percent of the eggs were laid in the next (middle external stratum). The lower external stratum had the lowest range (1-11%); however,

Table 12. Relationship between daily mean temperature (°C) and TPW oviposition in 6 tomato plant strata. Homestead, Florida, 1981.

Independent Variable x	Dependent Variable No. Eggs/stratum y	r^2*	r**	bo***	bl†
Temperature	upper internal	0.05	0.22	-0.007	0.005
	upper external	0.13	0.36	0.46	0.04
	middle internal	0.10	0.31	0.10	0.01
	middle external	0.02	0.14	0.02	0.0056
	lower internal	0.01	0.10	0.10	-0.02
	lower external	0.13	0.36	-0.11	0.01

*r^2 Coefficient of determination.

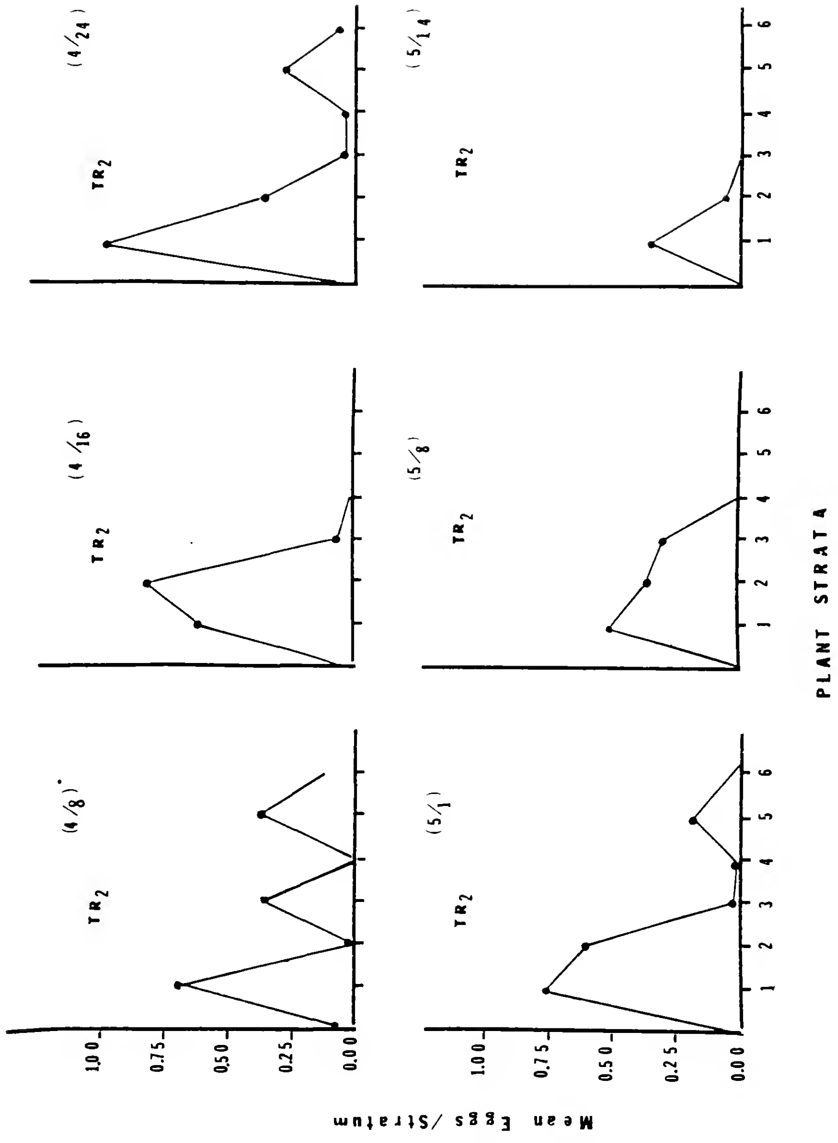
**r Correlation coefficient.

***bo Intercept of y axis.

†Slope.

Figure 6. Average number of tomato pinworm eggs per plant stratum during 6 different sampling dates in 2 tomato plantings at different growth stages. A) Planting 7: Jan. 30, 1981. B) Planting 8: Feb. 28, 1981. TR_2=second reproductive stage of development; TV_2=second vegetative stage of development. Plant strata: 1, 2, 3: upper, middle, lower external, 4, 5, 6: upper, middle, lower internal.

A



(4/8)
TR2
(4/16)
TR2
(4/24)
TR2
(5/1)
TR2
(5/8)
TR2
(5/14)
TR2
1.00
0.75
0.50
0.25
0.00
1 2 3 4 5 6
Mean Eggs/Stratum
PLANT STRATA

B

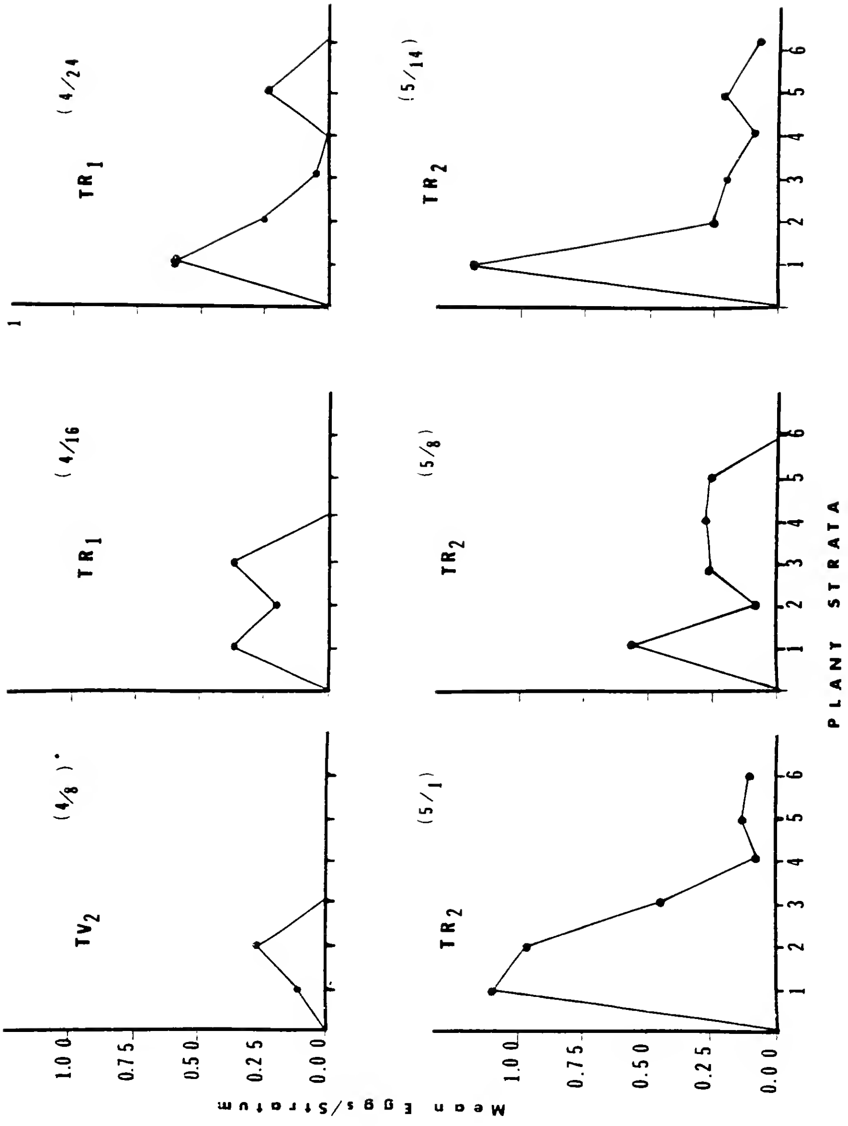

TV2
(4/8)
TR1
(4/16)
TR1
(4/24)
TR2
(5/1)
TR2
(5/8)
TR2
(5/14)
Mean Eggs/Stratum
1.00
0.75
0.50
0.25
0.00
PLANT STRATA
1
2
3
4
5
6

Table 13. Percentage distribution of TPW eggs for each stratum of tomato plants in 5 tomato plantings. Homestead, Dade County, Florida, 1980.

	Planting Date				
Stratum	Oct. 30 1980	Nov. 25 1980	Dec. 31 1980	Jan. 30 1981	Feb. 28 1981
Upper external	68	32	44	46	51
Middle external	4	15	23	28	21
Lower external	1	3	10	11	10
Upper internal	0	3	7	0.6	5
Middle internal	9	43	11	10	9
Lower internal	16	0.8	4	1	2

growth of the plant upwards and outwards can mislead my interpretation of actual ovipositional preference. The percentage of eggs found per internal stratum ranged from 0-7% in the upper internal, 9-43% in the middle internal, and 10-87% in the lower internal. TPW oviposits mainly in the upper external canopy when egg populations range from 0.75-1.5 and when the plant was in its reproductive stage. A lower proportion of eggs was found in all other strata.

Sampling 6 plant strata demonstrated that TPW tends to oviposit in the middle and upper canopy. It is necessary to use sample allocation (n_h), as outlined by Cochran (1977) to minimize sampling cost or variance (s^2). I assumed equal sampling cost for each stratum. Sample allocation was estimated on dates in which statistical differences in oviposition were detected.

In general, more samples should be allocated to the upper and middle external strata (Table 14). Because TPW eggs are clumped in the upper and middle canopy, these strata had the highest variance (see Appendix) (Tables 51-54). For a fixed total cost, $n = \dfrac{(C-C_o)\Sigma \dfrac{N_hS_h}{C_h},}{\Sigma N_hS_h/\ C_h}$ where $(C-C_o) = \sum_{i=1}^{L} C_in_i$, $nh = n \dfrac{W_hS_h}{\Sigma W_hS_h} = n \dfrac{NnS_h}{\Sigma N_hS_h}.$ Therefore as S_h increases so does nh. The average number (n=20) for all planting dates was 6, 5 and 3 samples from upper, middle and lower external canopy, and 1, 4 and 1 from upper, middle and lower internal canopy. Allocation ranged from 5-10 samples for the upper external canopy (see Appendix), and ranged from 2-8 samples for the middle external canopy. I considered this sample allocation to to be the best, because standard error (SE) of the sample mean was more

Table 14. TPW egg sample allocation for 6 plant strata during 3 different plant stages: second vegetative (TV_2), first reproductive (TR_1), and second reproductive stage (TR_2).

Plant Stage	Stratum					
	External			Internal		
	Upper	Middle	Lower	Upper	Middle	Lower
TV_2	8.59*	2.10	0	2.6	8.59	0
TR_1	5.70	5.75	8.24	0	0	0
TR_2	0	6.47	3.44	0	1.58	8.49
TR_2	5.96	5	2	1	4	2
TR_2	8.76	0	4	0	6	1
TR_2	4	3	6	2	4	0
TR_2	5	8	6	8	0	0
TR_2	5	5	0	1	2	0
TR_2	6	6	1	0	4	1
TR_2	9	4	2	0	5	0
TR_2	5	7	2	5	5	0
TR_2	5	5	2	0	3	0
TR_2	10	2	2	1	3	2
Average	6	5	3	2	4	1

*$n_h = \left(\frac{N_h S_h}{\sum_{i=1} N_h S_h}\right) n$; proportional allocation, assumes cost equal for sampling in each stratum.

constant through time (range: 0.20-0.66). There were exceptions for these sample allocations. For instance, during the month of February (planting 4), more numbers of samples were allocated to the lower internal stratum (see Appendix) (Table 54). Another aspect that requires more understanding is the relation between phenological stages and sample allocation. As an example, it was observed (see Appendix) that when plants were in vegetative stage (TV), more samples (n_h=18), should be allocated for the upper external and middle internal canopy. When plants are in first reproductive stage (TR_1), more samples (n_h=6), are allocated for upper external stratum. Finally, when plants reach the second reproductive stage (TR_2), all strata had similar sample allocations except for lower internal canopy (n_h=0).

Egg Distribution Influenced by Leaf Position

During heavy oviposition (avg 21.94 eggs per plant) on 45 day-old tomato plants, the highest number of eggs was observed on leaf number 4 (Table 15). The numbers of eggs on leaves 3 and 5 were statistically equal to those found on leaf 4. The number of eggs decreased sharply on leaves adjacent to the apical point toward the bottom of the plant (leaves 1-2). Tjese results indicated that middle leaves of 45 day-old plants under conditions of high egg oviposition (1-5.5 eggs per leaf) have 65% of the total egg population. These data differ from those obtained in experiment 1. The higher number of eggs per plant indicates that the insect tends to oviposit in the upper-middle canopy, avoiding the 2 top and bottom leaves of the plant. Several factors may influence the ovipositional pattern. First, these results agree with Hinton (1981),

Table 15. Mean tomato pinworm eggs on tomato leaves from different strata of 45 day-old plants. Homestead, Florida, 1980.

Leaf Position	Mean No. Eggs/Leaf	No. Leaflets/Leaf	Eggs/Leaflet
1 bottom	2.20[b*]	7	0.31
2	3.20[ab]	8	0.40
3 middle	5.40[a]	11	0.49
4	5.50[a]	11	0.50
5	5.00[a]	11	0.45
6 top	2.00[b]	8	0.25
7	1.00[b]	7	0.14

*Numbers followed by different letters were significantly different statistically at P=0.05 according to Duncan's Multiple Range Test.

who stated that species that lay eggs on plants have a marked preference for laying a certain height above the ground. Secondly, the insect may be avoiding overcrowding in the smaller top leaves and competition of foliar consumption by TPW larvae on the lower leaves. The highest sample (n=17) allocation was for leaves in the middle canopy (Table 16). Higher variance (s^2=44.4) was found for eggs deposited on those leaves, as was a high mean ($\bar{x}$=6.6). This is caused by egg clumping in the canopy. The fourth leaf had the highest allocation sample (n_h=5), followed by the fifth leaf (n_h=4). The lowest allocation was for the bottom leaf (n_h=1). The standard error of the mean sample was lowest (SE/$\bar{x}$=0.21), for the third leaf and slightly higher (SE/$\bar{x}$=0.24) for the fourth leaf. Therefore, when higher density and large variance are found, the leaves selected should be the middle ones. Sample allocation was reduced for bottom and top leaves. These leaves had smaller variance and smaller density than the middle ones.

Distances Between Eggs per Leaflet and Effect on Distribution

In the present study, the results indicated that TPW egg density was not related to leaflet area (Table 17). The coefficient of determination (r^2=0.026) indicated that females tend to oviposit different egg densities disregarding leaflet size. Therefore, any leaflet can be selected as the sampling unit. Frequency of egg occurrence per leaflet was not related to distance between eggs. Low coefficients of determination (r^2=0.19-0.23) between frequency of occurrence at different egg densities (2, 5 and 10 eggs/leaflet) and egg distances indicate lack of linear relationship between these variables. The slope (b1) obtained

Table 16. TPW egg sample allocation on tomato leaves numbered from bottom to top. Plants 45 days old.

Parameter	Leaf Number						
	1	2	3	4	5	6	7
$\bar{x}$	2	3.58	4.58	6.58	4.70	1.91	1.25
s^2	5.07	8.44	15.88	44.38	35.22	7.17	12.5
SE	0.60	0.83	0.96	1.61	1.43	0.77	1.25
Sh	2.25	2.90	3.98	6.66	5.93	2.67	3.53
$SE/\bar{x}$	0.30	0.23	0.21	0.24	0.30	0.40	1.00
n_h*	1	2	3	5	4	4	2

*$nh = \frac{(NhSh)}{\Sigma NhSh} n$, Nh=200, n=17.

Table 17. Relationship between frequency of occurrence of TPW eggs per leaflet as dependent variable and distance among eggs and leaflet area as independent variables.

Dependent Variable y	Independent Variable x	r^2*	r**	b_o***	b_1†
No eggs	Leaflet area	0.026	0.16	1.99[a]	0.04
2 TPW eggs	Distance among eggs	0.23	0.48	1.75[a]	-0.15[b]
5 TPW eggs	Distance among eggs	0.19	0.44	1.47[a]	-0.12[b]
10 TPW eggs	Distance among eggs	0.23	0.48	1.38[a]	-0.22[b]

*r^2=coefficient of determination.

**r=correlation coefficient.

***b_o=intercept of y asis.

†b_1=slope.

[a]numbers were highly statistically significant (P=0.01).

[b]numbers were statistically significant (P=0.05).

for any egg density was negative and highly significant (P=0.001). This can be explained in Fig. 7, where the frequency of egg occurrence at distances higher than 3 cm was as low as 5%. The average distance between eggs was 0.5-0.75 cm. The average number of eggs found on each leaflet was 2-3. These results agree with those expressed by Poe (1973); in the present study the number of eggs on each leaflet was as high as 11. Eggs tended to be laid more uniformly in some parts of the leaflet. Perhaps the female lays 2 eggs successively on a certain part of the leaflet, but is likely to move away after oviposition. The arrangement of eggs may also be a reflection of heterogeneity of conditions among parts of a leaflet such as pubescence and leaf venation. From the practical standpoint, these results can be used to determine use of single leaflets as less variable sampling units compared to the whole plant. A more detailed study of female behavior is necessary to determine the role of leaf factors (e.g., pubescence) affecting oviposition.

Differences in Oviposition Related to Plant Age

The relationship between oviposition and stage of plant development was determined during the study of plantings 4-8. Statistical differences were detected among these plantings (Table 18), when plantings were 19, 15, 11, 7 and 3 weeks old (stages S_1, TR_2, TR_1, TV_2, TV_1 respectively. The largest number of eggs was detected in planting 7, when this planting was in the TR_1 - TR_2 stages. At the same time, egg numbers decreased for planting 6 after the 10th week of plant growth. The mean number of eggs in planting 8 increased slightly from week 3 (TV_2), through 7 (TR_1). These data indicate that there may be several factors,

Figure 7. Frequency of tomato pinworm eggs at different distances (cm) between eggs when mean eggs were A) 2 eggs per leaflet and B) 5 eggs per leaflet.

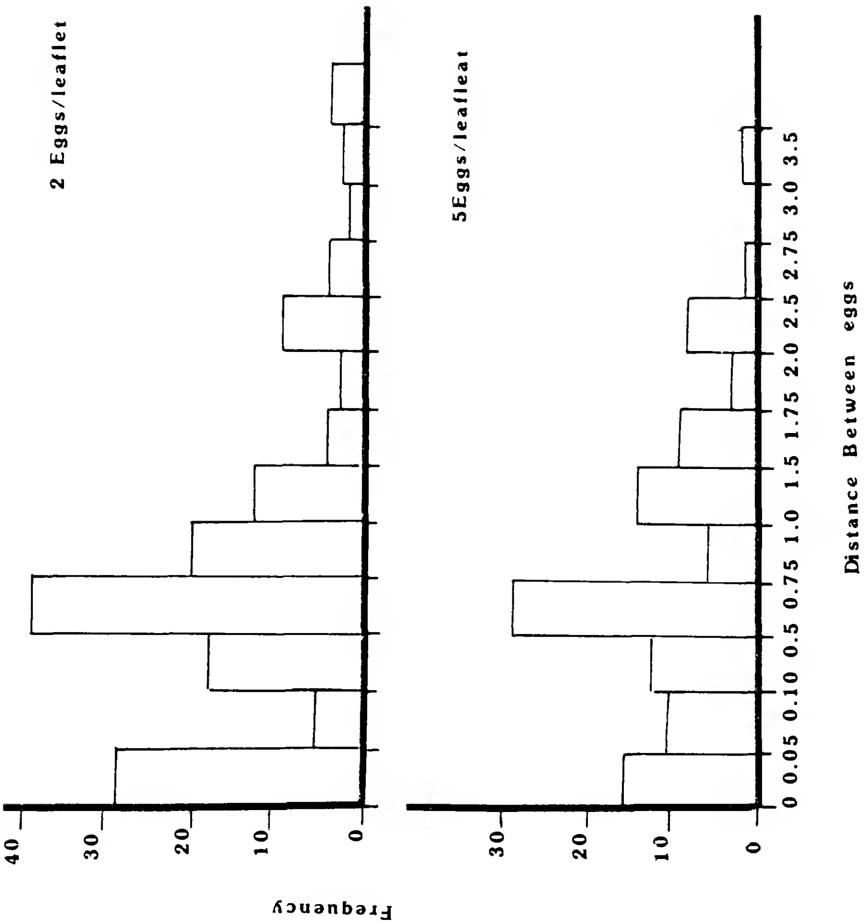

2 Eggs/leaflet
5Eggs/leafleat
Frequency
40
30
20
10
0
Distance Between eggs
0 0.05 0.10 0.5 0.75 1.0 1.5 1.75 2.0 2.5 2.75 3.0 3.5

Table 18. TPW oviposition on tomato at different plant stages. Homestead, Florida, 1981.

Planting Date	Date of Sampling						
	4/1	4/8	4/16	4/24	5/1	5/8	5/14
October	.05* (17)b** TR_3	.3(18)a TR_3	0.20(19)b TR_3	0.30(20)b S_1	1.3 (21)b S_1		
November	.10 (13)b TR_2	1.3(14)a TR_2	0.25(15)b TR_2	2.45(16)a TR_2	0.1 (17)b TR_3	0.7 (18)b TR_3	0.8 (19)b TR_3
December	1.9 (9)a TR_2†	1.2(10)a TR_2	0.75(11)ab TR_3	0.30(12)b TR_2	0.5 (13)b TR_2	1.0 (14)b TR_2	0.6 (15)b TR_2
January		1.6(6)a TR_1	1.5 (7)a TR_1	1.90(8)a TR_2	1.55(9)a TR_2	1.24(10)a TR_2	0.4 (11)b TR_2
February		0.4(2)a TV_1	1.0 (3)ab TV_2	1.1 (4)a TV_2	2.85(5)a TV_2	1.4 (6)a TR_1	2.65(7)a TR_1

*Numbers in parenthesis are weeks after emergence of crop.

**Numbers within a column followed by the same letters are not significantly different according to Duncan's Multiple Range Test ($P<0.05$).

†Stages of the tomato plant according to Chapter 1.

such as presence of inflorescence and water content associated with plant age, which account for frequency of TPW oviposition. The effect of plant water content in oviposition will be discussed in chapter 8.

General Discussion and Conclusions

Tomato pinworm egg distribution is one of the least studied aspects of this pest. In this research useful data were gathered about the spatial pattern of TPW eggs in the tomato plant, effect of plant age on oviposition, and use of these data for TPW egg sampling allocation.

The tomato pinworm tends to select certain leaf sides, plant strata and plant age for oviposition. TPW prefers ovipositing on the leaf underside. Ninety percent of the total eggs were laid in the leaf underside. Tomato pinworm oviposited mainly in the upper and middle plant canopy. Fifty-one percent of the eggs were laid in the upper canopy. There were exceptions to this rule. For instance, a crop planted during Oct. 30, 1980, in which sampling was done during January and February, had a higher than usual percent (17%), of eggs laid in the internal canopy.

The information described before was used to develop a sampling plan. First, 10-20 plants/acre can be used as sample size if a practical equilibrium between sampling cost per acre (33) dollars, and index of precision (54-31%), is desired. It was found that proportional sampling can be allocated for the upper external stratum (n_h=6), followed by the middle internal stratum (n_h=5), and 3, 1, 4 and 1 samples for lower external, upper, middle and lower internal canopy, respectively. Experiments also showed that under high density (22 eggs/plant) the insect prefers the middle leaves of the plant. These results were expected because TPW egg

population is considered clumped in the plant (k=0.01-0.45). The strata that has more eggs had higher variance than the strata with less oviposition. Therefore, more samples were allocated (n_h=4) to the middle stratum.

Also, the shortest range for a confidence interval of the mean was in the upper external stratum (0.51-1.7). At this time it is not known which is the economic threshold based on egg counts. The larval economic threshold is considered to be 1 larvae per plant (Chapter V), therefore, if no egg mortality is expected 1 egg per plant will be the economic threshold. The strata in which confidence intervals are less fluctuating through time are the upper and middle external canopies. Then, these strata are the ones to be selected for egg sampling in the field.

As expected, oviposition increased as plant age increased. More eggs were found on plants 4 weeks old (TV_2) than on plants 2 weeks old (TV_1). Egg numbers increased for plants 8-16 weeks old (TR_1 - TR_2), then decreased for plants 17-21 weeks old (TR_3-S). More research is nececessary to evaluate attraction for female oviposition based on physical and chemical qualities of the plant.

Leaflet area and egg density were unrelated (r^2=0.026). Distance between eggs was not influenced by egg density (r^2=0.19-0.23). The average distance between eggs per leaflet ranged from 0.5 to 0.75 cm. These results indicated TPW tendency to oviposit eggs at a common distance despite egg density and leaflet area.

CHAPTER IV
SPATIAL PATTERNS OF DISPERSION OF TOMATO PINWORM LARVAE IN TOMATOES

Introduction

Dispersion patterns of *Keiferia lycopersicella* (Wals.), tomato pinworm (TPW), larvae in tomatoes have not been studied in great detail. Knowledge of these patterns is necessary to develop a better sampling procedure. Several techniques for population estimates such as absolute, relative estimates and population indices are used to determine insect distribution (Southwood 1978).

The TPW larval population intensity method has been used by Wellik et al. (1979) to determine sampling accuracy. However, TPW population indices have only been used to measure economic damage (Wolfenbarger et al. 1975) and plant resistance (Schuster 1977a).

Because leaf mining lepidopterous larvae do not move from a given plant to neighboring ones (Dethier 1959, Nishijima 1960, Schoonhoven 1972) population indices can also be used to detect distribution patterns (Gomez and Bernardo 1974, Henson and Stark 1959, Condrashoff 1964). I used TPW damage index to (1) estimate dispersion patterns of TPW larvae during different plant stages, (2) determine an appropriate sample size and sample unit for TPW larval injuries, and (3) discuss sampling strategy.

Materials and Methods

Sampling Methods

To determine the relationship between damage by TPW on different strata of the tomato plant, 8 plantings of nonstaked tomatoes cv. 'Flora-Dade' (Nov. 3, 1979; Dec. 5, 1979; Jan. 8, 1980; Oct. 30, 1980; Nov. 25, 1980; Dec. 30, 1980; Jan. 30, 1981; and Feb. 28, 1981) were evaluated at the University of Florida Agricultural Research Center, Homestead, Florida. Each planting (ca. 450-947 plants) was direct-seeded in raised beds (3-5) (ca. 45 m long) of Rockdale soil, and mulched with light colored plastic. Seedbeds midlines were 182 cm apart. Plants were spaced 38 cm apart.

Sample size was selected by a preliminary random sampling of 50 plants on 2 dates. The method described by Elliott (1979) was adopted in this selection. The sample size was chosen at the point when TPW mine density variance stabilized. The percentage error that can be tolerated in the estimation of the population mean was expressed as the standard error of the mean. Finally, the cost of sampling within the plant (C_s) (Southwood 1978) and the cost of moving from 1 plant to another (C_p) were considered to estimate the relative net precision value ($RNP = \frac{100}{RV \times C_u}$), RV being the ratio $SE/\bar{x}$ and $C_u = C_p + C_s$.

Selection of the sampling unit for each plant was made by randomly collecting 1 leaf/plant, 2 leaves/plant and inspection of the whole plant (upper and lower canopy). The survey was made on 11 dates on

2 crops planted during Oct., 1979, and Dec., 1979. The mean per sample and standard error of the mean were estimated. The proportion of the true population collected per sample was determined by dividing the number of individuals per sample unit by the number on the whole plant and by comparing the RNP per sample unit.

After this, 20 plants in each planting were sampled by use of the simple random sample technique (Cochran 1977). Sampling was done on a weekly basis from Feb. 7, 1980, through May 29, 1981. The whole leaves of the plant were first examined to determine differences in larval injuries on lower and upper leaf surfaces (plantings 1-3) and then to detect differences in larval injuries in different plant strata (plantings 1-8). The plant was divided into 2 sections (upper and lower) for the first 3 plantings (1979-1980) and divided serially into 6 sections (upper, middle, and lower part of the external and internal canopy) for the last 5 plantings. After values of bilateral asymmetry of frequency distribution (kurtosis) have been obtained, data can be normalized (Sokal and Rohlf 1969). Data were transformed by replacing the value (x) by logarithm (x+1) (Elliott 1979). The counts were assessed by a t-test for results from plantings 1-3, and by analysis of variance (plantings 4-8). Means were separated by Duncan's Multiple Range Test (P=0.05).

Results and Discussion

Sample Size

Two goals were determined for sample size in tomatoes. One of them was an index of precision (I_p=25%) and the other was the cost of tomato

sampling in southern Florida ($7/acre). To accomplish this, sample size was selected based on 3 major criteria.

First, following the criteria outlined by Elliott (1979), a suitable sample size can be selected when the mean ceases to fluctuate (Table 19). It is observed that when average larval injuries run as low as 2.12 or as high as 11.05, injuries, variances and means tended to stabilize at ca. 20 plants.

Second, the use of index of precision ($I_p = SE/\bar{x}$) demonstrated that for low populations (0.2-2.12), $SE/\bar{x}$ ratio was between 91-24 when 20-50 plants were sampled (Table 19). It fluctuated between 20-29% for the 20-15 plants at populations above 10.93 injuries per plant. These results demonstrate that for lower insect populations it is necessary to increase the number of plants up to 50 and to reduce it to 15 when the population is as high as 11 injuries per plant.

Third, the sample number does reconcile with the actual budget. Cost of sampling larval injuries is 1.26 dollars less than the actual budget per acre if the sample size selected is 20. The use of relative net precision ($RNP = \frac{100}{RV \times C_u}$) can also be used for sample size selection. The larger the RNP of a sampling method, the greater the precision for the same cost. RNP values when population is low can be selected for an acceptable I_p. Therefore, RNP values can be accepted for 30-50 plants under such conditions. RNP values when the population is high can be selected for 25-50 plants. Nevertheless, to reconcile precision with cost, sampling 20 plants gave an acceptable RNP for high or low TPW populations.

Table 19. Sample size and relative net precision (RNP) for sampling tomato pinworm injuries at low and high population densities. Homestead, Dade County, Florida, 1980.

Larval Density	No. Plants Sampled	$\bar{x}$	s^2	s	SE	$(SE/\bar{x})$ x100	Cs[a]	Cp[b]	C total	RNP[c]
Low	5	0.2	0.2	0.44	0.2	100	0.83	0.6	1.43	0.69
	10	1.2	3.95	1.98	0.63	52.5	1.67	1.2	2.87	0.44
	15	1.26	3.78	1.94	0.501	39.76	2.50	1.80	4.3	0.58
	20	1.9	12.41	3.52	0.787	41.42	3.34	2.4	5.74	0.42
	25	2.12	11.52	3.39	0.67	31.6	4.17	3.00	7.17	0.44
	30	1.83	10.07	3.17	0.58	31.6	5.01	3.6	8.61	0.36
	50	1.58	7.3	2.7	0.38	24.05	8.35	6.0	14.35	0.28
High	5	17.2	212.6	14.6	6.5	37.84	0.83	0.6	1.43	1.84
	10	13.2	187.95	13.7	4.33	32.80	1.67	1.2	2.87	1.06
	15	10.93	153.5	12.4	3.2	29.2	2.5	1.8	4.3	0.79
	20	11.05	179.52	13.39	2.99	27.05	3.34	2.4	5.74	0.64
	25	12.24	173.77	13.18	2.63	21.48	4.17	3.0	7.17	0.64

Table 19--Continued.

30	11.86	148.91	12.2	2.22	18.71	5.01	3.6	8.61	0.62
50	11.14	120.51	10.97	1.55	13.01	8.35	6.00	14.35	0.53

[a] Cost per man h sampling: \$7.00; $t\alpha$; time per plant 1.43 min.; cost/plant = \$0.16 = Cs.

[b] Cp 1.06 min. to move from 1 pl. to another; cost in \$0.12 = Cp.

[c] $$RNP = \frac{100}{(RV) x (CV)}$$

Sampling Unit

Data from different numbers of leaves per plant in the upper and lower portions of the plant are shown in Tables 20-21. In Fig. 8 it is shown that it is necessary to select 2 leaves in the lower canopy if the number of injuries is as low as 0.03-0.55. This is 20-30% of the total number of injuries per plant. When the insect population increased, 2 leaves from the upper and lower parts were also necessary to obtain 32-34% of the total population. Selection of 1 leaf per plant from the upper portion gave as low percentages of the total damage as 1-2%, but increased during later sampling dates up to 9%. The number of injuries in 1 leaf per plant selected from the lower mid portion of the plant remained stable at about 10% with the highest being 16%.

Another aspect to consider for sample unit evaluation is the confidence interval of sample mean ($CI=\bar{x}\pm t_{\alpha} S_{\bar{x}}$). According to the results expressed in Tables 20-21, at low larval injury densities it is more appropriate to sample the whole plant. The confidence interval remained stable (0.24, -.08) for the whole plant until larval density was higher than 1. When density increased above 1, 2 leaves per plant gave a more stable confidence interval through time.

It is necessary to evaluate sample unit based on cost of sampling. Cost per sampling unit is shown in Table 22. Relative net precision was considered lowest when the whole plant was inspected. Two leaves from the lower canopy gave an acceptable RNP during 5 of the sampling

Table 20. Mean number of TPW foliar injuries and standard error on different sampling units at specified date. Crop planted in Nov., 1979. Homestead, Florida.

Sampling Unit	2/3 Upper	2/3 Lower	2/21 Upper	2/21 Lower	3/14 Upper	3/14 Lower	3/20 Upper	3/20 Lower	4/4 Upper	4/4 Lower
1 Leaf	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.08±0.05 (0.18, -0.02)*	0.16±0.09 (0.35, -0.3)	0.59±0.38 (1.37, -.19)	0.54±0.22 (.99, .08)	0.32±0.18 (.69, -.05)	1.44±0.27 (1.99, .88)
2 Leaves	0.00±0.00	0.04±0.04 (.12, -.04)	0.00±0.00	0.00±0.00	0.24±0.11 (.46, .01)	0.55±0.21 (0.98, .11)	0.76±0.24 (1.25, .26)	1.16±0.35 (1.88, .43)	0.88±0.26 (1.41, .35)	1.88±0.41 (2.72, 1.03)
Whole Plant	0.00±0.00	0.12±0.08 (.28, .04)	0.00±0.00	0.08±0.08 (.24, -.08)	1.66±0.37 (2.42, .89)	4.77±1.38 (2.87, 1.92)	1.32±0.26 (1.85, .78)	4.32±1.01 (6.39, 2.24)	3.6±0.52 (4.67, 2.52)	4.84±0.75 (6.38, 3.29)

*95% confidence limits.

Table 21. Mean number of TPW foliar injuries and standard error on different sampling units at specified date. Crop planted in Jan., 1980. Homestead, Florida.

Sampling Unit	2/8		2/12		2/25		3/14		3/20	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
1 Leaf	0.83±0.13 (.34, -.16)*	0.21±0.09 (.39, .02)	0.05±0.05 (.15, -.05)	0.10±0.07 (.23, .03)	0.25±0.1 (.45, .04)	0.32±0.12 (.56, .07)	0.50±0.20 (.83, .12)	0.70±0.22 (1.13, .22)	0.24±0.10 (.45, .02)	0.36±0.95 (.55, .16)
2 Leaves	0.16±0.10 (.37, -.05)	0.41±0.20 (.81, .01)	0.10±0.10 (.30, -.10)	0.15±0.08 (.31, -.01)	0.64±0.3 (1.25, .02)	0.68±0.18 (1.05, .30)	0.72±0.14 (1.0, .43)	1.16±0.24 (1.65, .66)	0.44±0.20 (.85, .02)	1.12±0.14 (1.7, .83)
Whole Plant	0.76±0.10 (1.08, -.05)	1.33±0.43 (2.21,. 44)	0.55±0.24 (1.04, .05)	0.45±0.18 (.82, .07)	1.44±0.44 (2.34, .53)	2.00±0.42 (2.86, 1.13)	5.48±0.71 (6.94, 4.0)	6.72±0.97 (8.71, 4.72)	3.92±0.34 (4.62, 3.21)	6.12±0.38 (5.33, 6.9)

*95% confidence limits.

Figure 8. Percentage of tomato pinworm (TPW) larval injuries in 2 sampling units from different plant portions, related to number of injuries in the whole plant: 1) 1st planting, Nov. 3, 1979; 2) 3rd planting, Jan. 8, 1980.

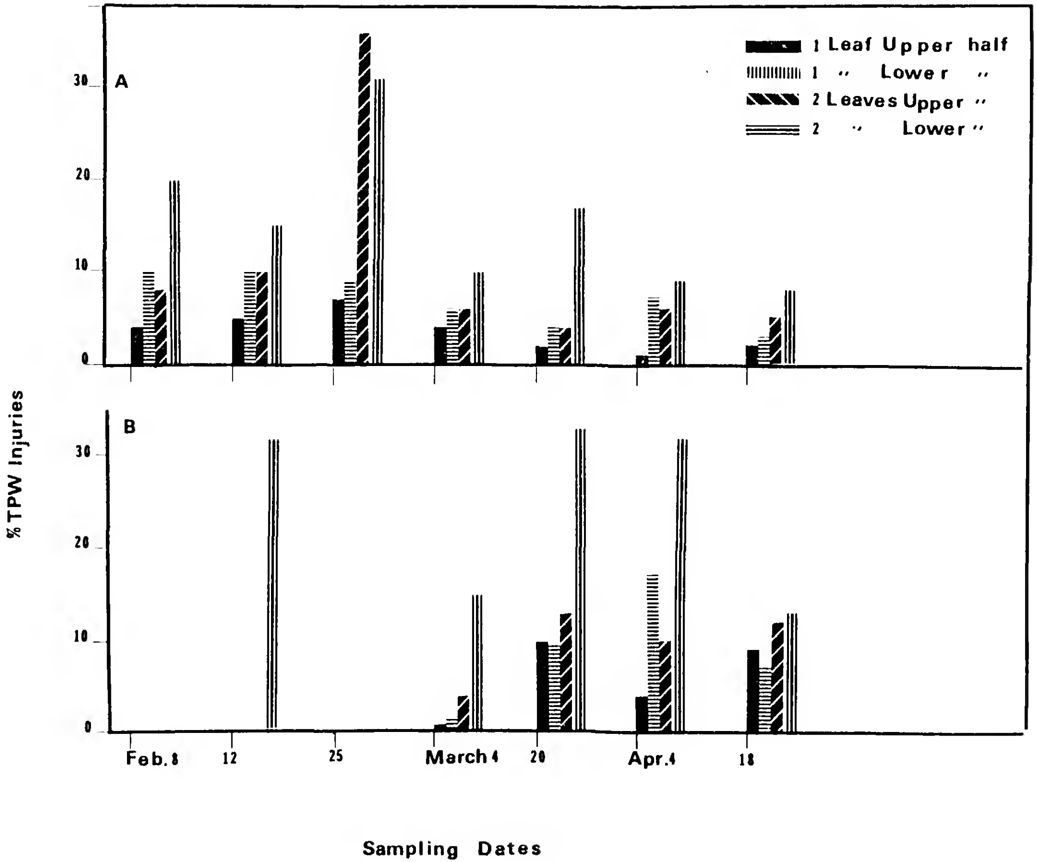

A
B
1 Leaf Upper half
1 " Lower "
2 Leaves Upper "
2 " Lower "
30
20
10
0
% TPW Injuries
Feb. 8
12
25
March 4
20
Apr. 4
18
Sampling Dates

Table 22. Sample size and relative net precision (RNP) for sampling TPW larval injuries on upper and lower plant canopy. Homestead, Florida, 1980.

Sampling Unit	Sampling Date													
	2/8		2/12		2/25		3/14		3/20		4/4		4/18	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
1 Leaf*	0.75**	0.20	0.50	0.12	0.80	0.22	1.41	0.25	1.16	0.31	1.09	0.76	1.33	0.23
2 Leaves	0.07	0.11	0.04	0.10	0.09	0.20	0.22	0.25	0.10	0.42	0.21	0.37	0.14	0.19
Whole Plant	0.02	0.03	0.02	0.02	0.03	0.05	0.07	0.67	0.11	0.15	0.07	0.08	0.08	0.10

*Cs = 1 leaf upper = 0.02 min-man
1 leaf lower = 0.12 min-man
2 leaves upper = 0.23 min-man
2 leaves lower = 0.19 min-man
Whole Pl. upper = 1.43 min-man
Whole Pl. lower = 1.43 min-man

**$RNP = \frac{100}{RV \times Cs}$

sampling dates. The highest RNP was obtained from sampling 1 leaf. A sound sampling program requires precision and depends on resources. A balance must be struck between the two to keep variance minimal for fixed costs. Emphasis must always be given to practical considerations (Ramsany 1980). In general, 2 leaves from the lower canopy should be used as a sampling unit when a stable RNP is desired.

Statistical Distribution of TPW Larval Injuries

Different procedures were used to detect data normality. The statistics summarized in Table 23 suggest a larval aggregation of TPW in the tomato plant foliage. In general, as the mean increases, variance also increases. The variance to mean ratio, or index of dispersion (I) will approximate unity if there is agreement with a Poisson series. The (I) values obtained were far from unity. Values ranged from 2.45 to 6.05. Values of skewness and kurtosis were all positive. This means that frequency distribution of larval counts tails off among the higher counts. Values of the k from negative binomial distribution are considered more clumped when k approaches zero. The lowest value found in this data was k=0.21. The Poisson distribution, however, fitted (P=0.005) 34% of the sampling dates (see Appendix). In general, TPW injuries were considered clumped in the tomato plant.

Distribution of Injuries on Upper and Lower Portions of the Plant

Statistically significant differences (P=0.05) were detected for the injuries located in the lower part of the plant for the 5 sampling dates in the first planting (Table 24). Statistical differences were

Table 23. Sample statistics: Mean tomato pinworm larval injuries per plant in 8 tomato plantings. Homestead, Florida, 1979-81.

Planting No./Date		N	$\bar{x}$	S^2	S	Skewness	Kurtosis	k*	I**
1	Nov. 3, 1979	525	3.76	22.77	4.76	2.59	9.73	0.743	6.05
2	Dec. 5, 1979	240	2.49	14.65	3.82	3.33	18.22	0.509	3.83
3	Jan. 8, 1980	596	2.40	12.07	3.47	2.81	14.35	0.59	5.02
4	Oct. 30, 1980	882	0.40	1.13	1.06	3.9	19.84	0.21	2.82
5	Nov. 25, 1980	894	0.41	1.13	1.06	3.92	19.42	0.23	2.76
6	Dec. 30, 1980	1019	0.49	1.37	1.17	3.25	12.78	0.27	2.79
7	Jan. 30, 1981	953	0.39	0.97	0.98	3.35	13.30	0.26	2.48
8	Feb. 28, 1981	717	0.35	0.86	0.93	3.65	17.33	0.24	2.45

* $k = \dfrac{\bar{x}}{\frac{S^2}{\bar{x}} - 1}$

** $I = \dfrac{S^2}{\bar{x}}$

Table 24. Mean tomato pinworm (TPW) foliar larval injuries at 2 different plant levels for 3 different plantings. Homestead, Dade County, Florida, 1980.

Planting	Strata	Mean TPW Leaf Injuries* per Stratum on Specified Date														
		2/8	2/12	2/21	2/29	3/7	3/14	3/20	3/27	4/3	4/11	4/24	5/2	5/9	5/20	6/2
1	Upper	0.87b**	0.55a	1.44a	2.04a		5.48a	3.92a		8.68b	7.32b	5.04a	11.8a	8.64a	5.6a	10.4a
	Lower	1.33a	0.45a	2.00a	2.24a		6.72a	6.12a		16.8a	11.84a	7.32b	11.76a	8.30a	5.7a	5.6a
2	Upper	0.00	0.00	0.00	0.00	0.7a	1.8a	3.0b	2.7a	4.3a	7.4a	6.5a	4.8a	4.2a	3.4a	6.3a
	Lower	0.04	0.33	0.08	0.16	1.36	5.3a	4.7a	3.5a	8.1a	7.0a	5.2a	3.3a	3.1a	1.9a	4.7a
3	Upper		0.00	0.00	0.00	0.04a	0.08a	0.00	0.8b	2.3b	3.5b	13.2a	7.8a	7.6a	1.5a	1.3a
	Lower		0.00	0.00	0.00	0.12a	0.16a	0.08	1.7a	8.3a	6.6a	7.4b	4.3b	4.4b	0.36a	0.8a

*Data transformed back to the original units after statistical analyses have been carried out from the transformed data.

**Means followed by the same letter in the same planting and date are not significantly different at P=0.05, according to Students t-test.

only detected once for the second planting. In general, the lower part of the plant had 60% more injuries than the upper half during the first 4 sampling weeks for the first planting (Nov., 1979). Also, the upper half had zero injuries during the first 4 sampling weeks. When plantings 1, 2, and 3 were 16 (TR_3), 12 (TR_2), and 8 (TR_2) weeks old, respectively, there were similar numbers of injuries in the lower (55%) and upper (45%) parts of the plant in planting 1. In planting 2, 75% of the injuries occurred in the lower half and planting 3 had 67% in the lower half. Nevertheless, the number of injuries in each stratum was not significantly different. There were more injuries in the upper part of the plant when the plantings were 21 (S_1), 17 (TR_3), and 13 (TR_2) weeks old. This may indicate more active larval consumption in the lower half of younger plants and fewer injuries in that level in older plants. These results disagree with the Florida results of Wolfenbarger et al. (1975), but are in agreement with those of Wellik et al. (1979) in Texas.

Distribution of TPW Foliar Injuries in 6 Plant Strata

Statistically significant differences were detected for 3 of the 16 sampling dates for planting 4 (Nov., 1980) (Table 25). Greater numbers of larval injuries were found in the middle internal, lower external, and lower internal canopies. When data were converted into percentages and analyzed, there were significant differences between the lower portion of the plant and other strata (Fig. 9-10). The number of foliar injuries for planting 5 (Oct., 1980) showed statistically significant differences in 1 sampling date. Greater damage was recorded from the

Table 25. Mean tomato pinworm (TPW) larval injuries in 6 plant strata for 5 plantings. Homestead, Dade County, Florida, 1981.

Planting	Stratum	Sampling Date															
		1/27	2/4	2/10	2/16	2/25	3/3	3/11	3/18	4/1	4/8	4/16	4/24	5/1	5/8	5/15	5/29
4	Upper Ext.	0.00	0.00	0.00	0.05	0.1*	0.05	0.0b**	0.2a	0.4b	0.25a	0.3a	0.4a	0.8ab	0.6a	0.5a	0.7a
	Upper Int	0.00	0.00	0.00	0.00	0.00	0.00	0.00b	0.05a	0.3b	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a
	Middle Ext.	0.00	0.00	0.00	0.00	0.1	0.2	0.1b	0.3a	0.3b	0.55a	0.4a	0.5a	0.7ab	1.2a	1.5a	1.2a
	Middle Int.	0.00	0.00	0.1	0.0	0.05	0.6	0.3a	0.9a	0.6b	0.4a	0.1a	0.3a	0.95ab	0.0a	0.0a	0.0a
	Lower Ext.	0.00	0.00	0.00	0.00	0.05	0.4	0.1b	0.05a	0.9a	0.05a	0.3a	0.6a	0.3b	0.5a	2.6a	1.8a
	Lower Int.	0.00	0.00	0.05	0.0	0.2	0.3	0.2ab	0.2a	0.0	0.2a	0.5a	0.1a	0.55ab	0.0a	0.0a	0.0a
5	Upper Ext.	0.00	0.00	0.00	0.00	0.00	0.00	0.05a	0.1a	0.0a	0.4a	0.35b	0.1b	0.9a	0.4a	0.2a	0.3a
	Upper Int.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.1a	0.0a	0.0b	0.0b	0.3a	0.0a	0.0a	0.0a
	Middle Ext.	0.00	0.00	0.00	0.00	0.00	0.00	0.2a	0.3a	0.4a	0.6a	0.3b	0.1b	1.2a	0.8a	2.6a	0.8a
	Middle Int.	0.00	0.00	0.00	0.00	0.00	0.00	0.05a	0.4a	0.2a	0.6a	0.35b	0.1b	0.1a	0.2a	0	0
	Lower Ext.	0.00	0.00	0.00	0.00	0.00	0.00	0.05a	0.3a	0.2a	0.6a	0.75a	0.7a	0.3a	0.8a	3.5a	0.8a
	Lower Int.	0.00	0.00	0.00	0.00	0.00	0.00	0.05a	0.05a	0.1a	0.5a	0.0b	0.4b	0.4b	0.0a	0.1a	0.0a
6	Upper Ext.				0.0	0.0	0.0	0.0	0.0a	0.0a	0.0a	0.2ab	0.9b	0.75a	1.1a	1.abc	0.15b
	Upper Int.				0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0b	0.0b	0.0a	0.1a	0.1c	0.0b

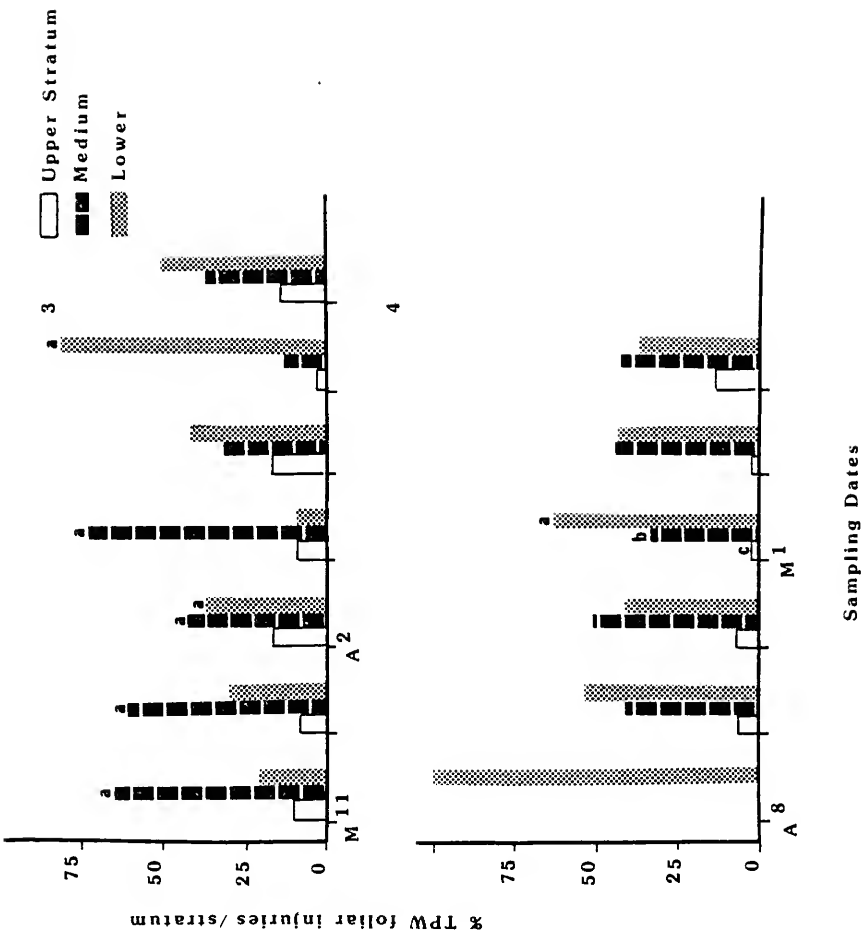
Table 25--continued.

	Middle Ext.	0.00	0.0	0.0	0.0	0.0	0.1a	0.15a	0.45ab	1.4a	1.15a	0.5a	1.9ab	0.85a
	Middle Int.	0.00	0.0	0.0	0.0	0.1a	0.1a	0.15a	0.10b	0.85b	1.7a	0.7a	0.6bc	0.3b
	Lower Ext.	0.00	0.00	0.00	0.0	0.0a	0.1a	0.15a	0.6a	0.9b	2.5a	1.8a	3.3a	0.7a
	Lower Int.	0.00	0.00	0.00	0.00	0.1a	0.1a	0.0a	0.2ab	0.25b	1.1a	0.4a	0.2c	0.2b
7	Upper Ext.						0.0	0.0a	0.1ab	0.2a	0.05a	0.25b	0.3a	0.2bc
	Upper Int.						0.0	0.0a	0.0ab	0.0	0.0	0.0a	0.0	0.1c
	Middle Ext.						0.0	0.05a	0.1ab	1.1	0.55a	0.5b	1.1a	0.8a
	Middle Int.						0.00	0.00a	0.45ab	0.15	0.35a	1.0b	0.7a	0.1c
	Lower Ext.						0.00	0.00a	0.55a	0.25	1.3a	2.1a	1.7a	0.8ab
	Lower Int.						0.00	0.00a	0.2ab	0.65	0.7a	0.0b	0.1a	0.0c
8	Upper Ext.						0.0	0.05a	0.0	0.0	0.1	0.15	0.7b	0.7ab
	Upper Int.						0	0.0a	0	0.1a	0.0a	0.0a	0.0b	0.0ab
	Middle Ext.						0	0.0a	0	0.15a	0.3a	1.2a	1.55ab	0.3ab
	Middle Int.						0	0.0a	0	0.05a	0.5a	0.8a	0.8b	0.6ab
	Lower Ext.						0	0.0a	0	0.15a	0.7a	1.1a	1.8ab	0.9a
	Lower Int.						0	0.0a	0	0.1a	0.3a	0.3a	0.3a	0.2ab

*Data retransformed to the original units after statistical analysis.

**Numbers within a column by planting followed by the same letter are not significantly different according to Duncan's Multiple Range Test.

Figure 9. Percentage of tomato pinworm (TPW) foliar injuries found at upper, medium, and lower stratum in 4 tomato plantings: 1) Oct. 30, 1980; 2) Nov. 25, 1980; 3) Dec. 30, 1980; and 4) Jan. 30, 1981. Bars followed by different letters were significantly different according to Duncan's Multiple Range Test ($P=0.05$). Percentages were previously transformed to arc sine. Percentages are expressed as actual numbers before transformations.


Upper Stratum
Medium
Lower
% TPW foliar injuries /stratum
Sampling Dates
M 11
A 2
3
A 8
M 1
4
75
50
25
0

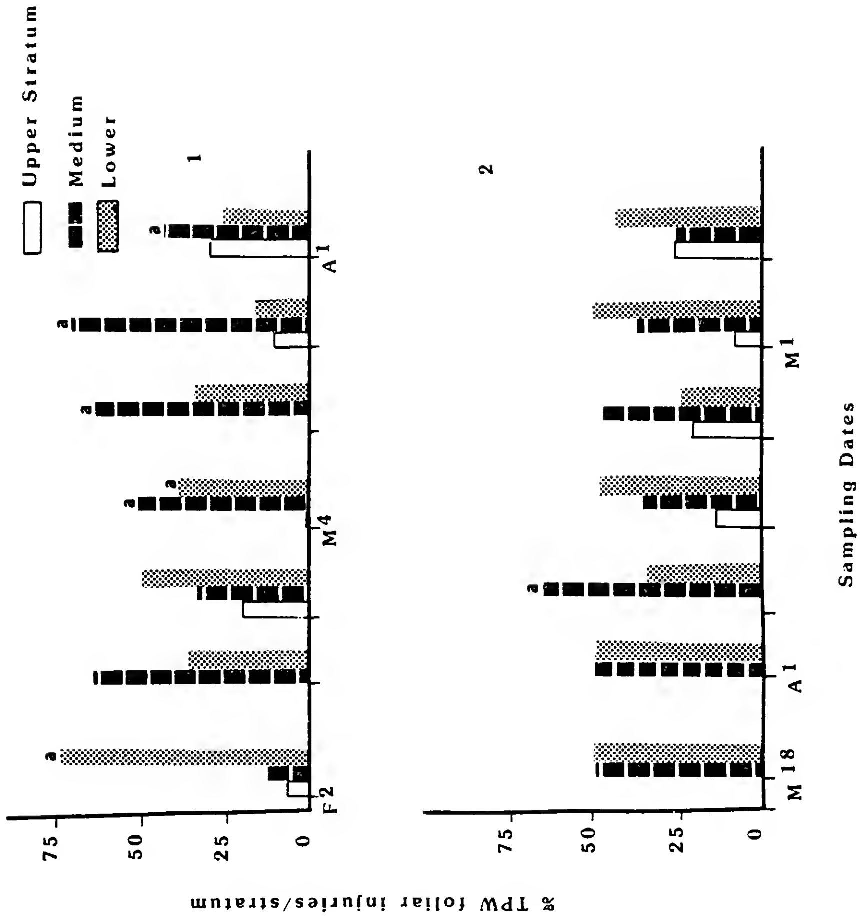
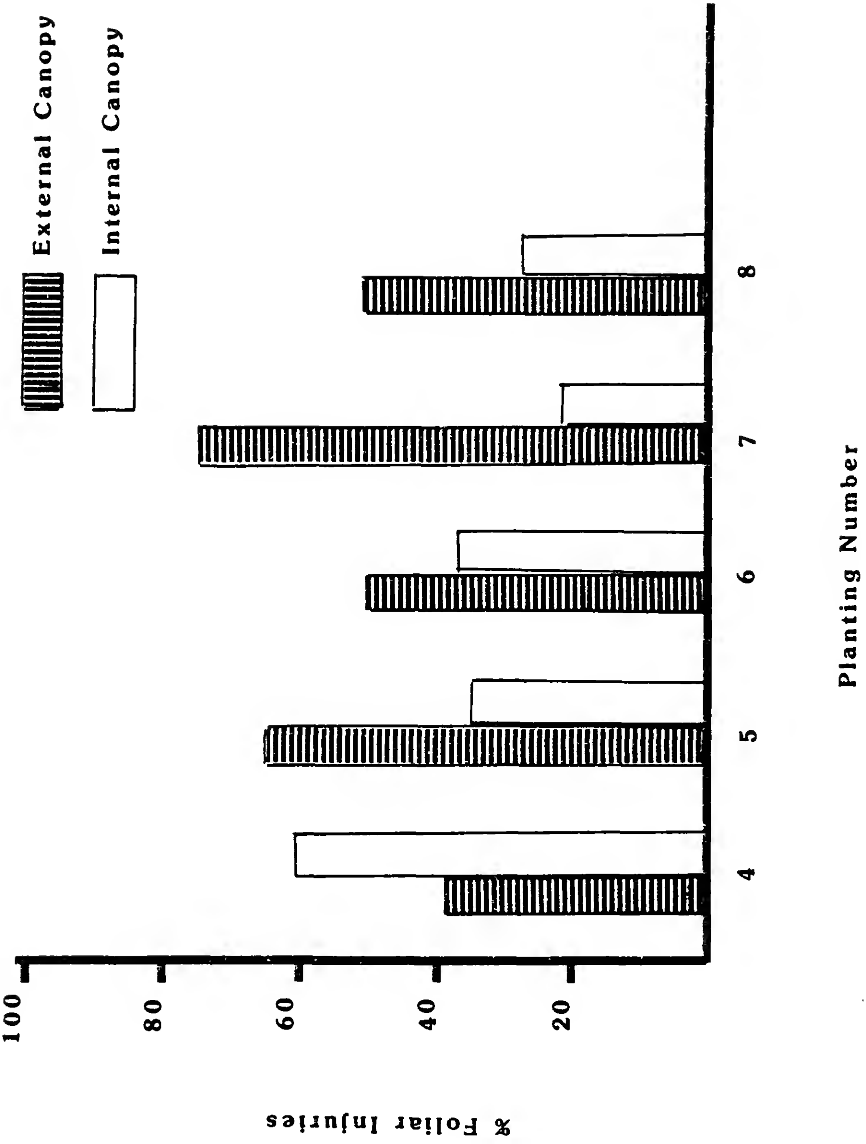

Upper Stratum
Medium
Lower
1
2
% TPW foliar injuries/stratum
75
50
25
0
F 2
A 1
M 4
M 18
M 1
Sampling Dates
a

Figure 10. Percentage of larval injuries at the external and internal canopy evaluated from 5 tomato plantings. Plantings 4, 5, and 6 planted in Oct., Nov., and Dec., 1980; Plantings 7 and 8 planted in Jan. and Feb., 1981. Homestead, Florida, 1980-81.


External Canopy
Internal Canopy
% Foliar Injuries
100
80
60
40
20
4
5
6
7
8
Planting Number

lower external canopy. During the 14-16 weeks of plant development, the lower, middle, and upper canopy contained 91, 88, and 88% of larval injuries, respectively. Larvae tended to occupy the upper part of the plant in older plantings (18-20 weeks). Statistical differences for the crop planted on Dec., 1980 were observed in 4 of the sampling dates. More extensive larval injury was found in the lower external and middle external canopy. When plants were 10-15 weeks old, higher proportions of injuries (99-100%) again were found in the middle and lower canopy. Statistical differences for the crop planted in Jan., 1981 were observed in 3 of the 7 sampling dates. Higher percentages of numbers of injuries were found (98-100%) when the crop was 9-15 days old. Larger numbers of injuries were recorded for the upper external part of the plant for planting 8 (Feb., 1981) during 1 sampling date.

Sampling 6 strata demonstrated that TPW larval injuries are significantly higher in the middle and lower canopy. Sample allocation (n_h) as outlined by Cochran (1977) is necessary to minimize variance (S^2). Sample cost was considered equal for each stratum. Sample allocation was estimated on dates in which statistical differences were detected.

In general, more samples should be allocated to the middle and lower strata (Table 26). The average numbers (n=20) for all plantings were 2, 3, and 5 samples for upper, middle and external canopy, and 0.09, 5, and 3 from upper, middle, and internal canopy. Allocation ranged from 0-20 samples for the lower external canopy, and ranged from 0-9 samples for the lower internal canopy. I considered this sample allocation to be the best, because standard error (SE) of the sample mean was more constant through time (range:0.20-0.66).

Table 26. TPW larval injury sample allocation for 6 plant strata at 3 different plant stages: second reproductive (TR_2), third reproductive (TR_3) and senescent (S_1).

	Stratum					
	External			Internal		
Stage	Upper	Middle	Lower	Upper	Middle	Lower
S_1	4*	3	6	0	4	0
S_1	1	3	1	0	5	4
S_1	0	5	9	0	6	0
TR_2	0	0	20	0	0	0
TR_2	2	2	5	0	5	2
TR_2	0	0	0	0	12	4
TR_2	4	5	4	0	5	2
TR_3	2	1	2	0	2	9
TR_3	2	4	5	1	4	2
TR_3	1	2	5	0	5	4
TR_3	5	5	2	0	2	6
Avg.	2	3	5	0.09	5	3

*$n_h = \left(\frac{N_h S_h}{\Sigma N_h S_h}\right) n$; n = 20, N = 947.

There were exceptions to these sample allocations. Allocation increased for the upper canopy when plants were in the second reproductive stage (TR_2) and during the senescent stage (S_1). It is necessary to correlate this sample allocation with fruit damaged in different parts of the plant canopy. Knowledge of this relationship will help in better prediction of yield losses.

Larval Injuries at Different Plant Growth Stages

The relationship between TPW foliar larval injuries and stage of plant development was determined during the study of plantings 4-8 (Table 27). For the earlier planting (Oct., 1980), the mean number of TPW injuries appeared during the second reproductive stage (TR_2) and peaked during the senescent (S_1) stage. On later plantings (Nov.-Dec., 1980) TPW larval infestation was not observed until the second reproductive stage (TR_2), when plants were 14 and 11 weeks old, respectively. Higher foliar infestation was obtained when plants were in the late reproductive stage (TR_3) and also in the senescent stage. For the winter season plantings (Jan.-Feb., 1981) injuries were first observed during the second reproductive stage. The reason for differences in larval infestation in different crops can be related to several factors. First, there was a low oviposition rate in the earlier planting (Oct.-Dec.). Secondly, the earlier fall crop (Oct., 1980) had a dense leaf canopy and approached the senescent stage later than the other plantings (Table 2). Thus, infestations in this planting were probably influenced by a complex of factors, including increased food consumption by the pest during the senescent stage due to reduction of food quality.

Table 27. Mean number and standard error of tomato pinworm (TPW) injuries in 5 different plantings at specified date and plant growth stage.

Planting	Sampling Dates*							
	1/27	2/4	2/10	2/16	2/25	3/3	3/11	3/18
Oct.-80	0** TR_2 (13)	0.06 ± 0.17 TR_2 (14)	0.15 ± 0.08 TR_3 (15)	0.05 ± 0.05 TR_3 (16)	0.55 ± 0.3 TR_3 (17)	1.4 ± 0.45 TR_3 (18)	0.6 ± 0.23 S_1 (19)	1.7 ± 0.72 S_1 (20)
Nov.-80	0 TR_2 (8)	00 ± 0.00 TR_2 (9)	0.00 TR_2 (10)	0.00 TR_2 (11)	0 TR_2 (12)	0 TR_2 (13)	0.4 ± 0.13 TR_2 (14)	1.05 ± 0.69 TR_3 (15)
Dec.-80				0.00 TR_1 (7)	0.00 TR_2 (8)	0 TR_2 (9)	0 TR_2 (10)	0.20 ± 0.15 TR_2 (11)
Jan.-81							0 TV_2 (5)	0 TR_1 (6)
Feb.-81							0 TV_1 (1)	0 TV_1 (2)

Table 27--Continued.

	4/1	4/8	4/16	4/24	5/1	5/8	5/15	5/29
Oct.-80	2.1$\pm$1.11 S_1 (22)	1.3+0.30 S_1 (23)	1.6$\pm$0.53 S_1 (24)	1.7$\pm$0.39 S_1 (25)	5.9+0.93 S_1 (26)	2.3$\pm$0.63 S_1 (27)	4.6$\pm$1.21 S_1 (28)	3.7$\pm$0.36 S_1 (29)
Nov.-80	0.8$\pm$0.31 TR_3 (17)	3.55$\pm$1.45 TR_3 (18)	1.75$\pm$0.33 S_1 (19)	1.15$\pm$0.29 S_1 (20)	6.1$\pm$1.06 S_1 (21)	2.0$\pm$0.66 S_1 (22)	6.6$\pm$0.20 S_1 (23)	1.9$\pm$0.70 S_1 (24)
Dec.-80	0.3$\pm$0.11 TR_2 (12)	0.45$\pm$0.22 TR_2 (13)	1.8$\pm$0.32 TR_2 (14)	4.25$\pm$0.76 TR_2 (15)	10.15$\pm$1.18 TR_3 (16)	4.4$\pm$0.88 TR_3 (17)	6.6$\pm$0.8 TR_3 (18)	2.2$\pm$0.44 S_1 (19)
Jan.-81	0 TR_2 (8)	0.05$\pm$0.05 TR_2 (9)	1.3$\pm$0.37 TR_2 (10)	2.25$\pm$0.5 TR_2 (11)	2.9$\pm$0.62 TR_2 (12)	3.85$\pm$0.33 TR_2 (13)	3.8$\pm$0.7 TR_2 (14)	1.9$\pm$0.3 TR_3 (15)
Feb.-81	0 TV_2 (4)	0.05$\pm$0.05 TV_2 (5)	0 TR_1 (6)	0.55$\pm$0.2 TR_1 (7)	1.6$\pm$0.46 TR_2 (8)	3.85$\pm$0.45 TR_2 (9)	5.05$\pm$0.93 TR_2 (10)	2.25$\pm$0.47 TR_2 (11)

* Plantings were sampled during 1981.

** Mean number of TPW foliar injuries, standard error of the mean plant growth stage, plant age in weeks. Plant stages: TR = Reproductive, S_1 = Senescent, TV = vegetative.

General Discussion and Conclusions

In this research useful data were gathered about the use of TPW damage index to estimate TPW larval patterns during different plant stages and about selecting an appropriate sample size and unit.

The population index used (TPW larval injuries/plant) indicated that during plant stage TV_2, TPW damage range (0.0-0.05) is lower than that found in reproductive stages (TR_1=0-0.55, TR_2=0-5.05, TR_3=0.8-10.15), and lower than the estimates from the senescent stage (S_1=0.6-6.6). Further information is needed to detect if nutritional changes in the plant are the major factor for higher or lower number of injuries per plant. The information is also necessary for detailed plant resistance studies.

The information supplied by sample size can be used to develop a sampling plan. For instance, 20 plants/acre can be used as sample size when a practical equilibrium between index of precision (I_p) and cost (RNP) is desired. The sampling unit to be selected is 2 leaves/plant from the lower canopy when an acceptable (RNP=0.25 or less) is found. This information can be used for commercial sampling for detection of foliar injuries. One of the problems involving this selection is that TPW foliar injury does not necessarily mean fruit injury. Therefore, establishment of a relationship between fruit and leaf damage is needed. Sample allocation resulted in a major proportion of samples allocated to the middle and lower canopy. When total sample size equals 20, n_h=8

samples should be taken from the middle as well as from the lower canopy. An $n_h=2$ should be allocated for the upper canopy.

These results were expected because TPW injuries were considered clumped in the tomato plant. The values obtained from the index of dispersion ($I=\frac{s^2}{\bar{x}}$) ranged between 2.45-6.05. This departure from unity means TPW larval aggregation in the plant. The data can be used to transform larval counts in order to obtain normalization. If sequential sampling is projected, it is necessary to find a common k value for TPW injuries.

The population index should be incorporated into a more sophisticated damage and population evaluation method. For instance, techniques such as degree of damage (Chapter 2) would be useful together with the population index. The combination of these techniques will help the scout in detection of larval populations approaching economic thresholds.

CHAPTER V
TOMATO PINWORM ARTIFICIAL INFESTATION: EFFECT OF FOLIAR AND FRUIT INJURY ON GROUND TOMATOES

Introduction

Economic losses resulting from insect injury to the foliage and fruit are difficult to measure. One of the problems in determining an economic threshold of a pest species is to distinguish between its mere presence in a crop and the density that will cause an unacceptable loss quality or quantity (Stern 1973). Damage to the tomato fruit by the tomato pinworm, *Keiferia lycopersicella* (Wals.), has been evaluated by Poe and Everett (1974), Wolfenbarger et al. (1975) and Wellik et al. (1979). The results were contrary in the three studies. Poe and Everett (1974) found no correlation between leaves mined and presence of larvae and fruit loss. Wolfenbarger et al. (1975) determined that TPW damage to the 3 top leaves could be associated with fruit injury. Wellik et al. (1978) indicated that damaged lower leaves and large fruit are the best for estimating *K. lycopersicella* infestations. Waddill (1975) and Schuster and Everett (1982) show estimates for losses from TPW natural infestations.

In this study, two techniques for estimation of TPW fruit loss are assessed: (1) use of TPW larval artificial infestation to measure yield reduction and (2) use of the population index (TPW foliar injuries) and

its relation to yield losses. In addition, fruit damage related to time of planting is examined, and the effect of plant pruning on TPW fruit damage is evaluated.

Materials and Methods

First Experiment

Reductions in 'Flora-Dade' tomato yield caused by different population levels of TPW were measured during 1980 and 1981 at the Agricultural Research Center, Homestead, Florida. Crops were direct-seeded on December 5, 1979; January 8, December 1980; December 30, 1980; and January 30, 1981. Plots were thinned to one plant every 0.30 m. Seedbed's midlines were 182 cm apart. Each crop was sprayed weekly with fenvalerate 2.4EC at a rate of 0.064 kg ai/ha. Insecticide application was discontinued 25 days before artificial infestation with TPW second instar larvae. Larvae were reared on tomato plants in a greenhouse at $23\pm2^{o}C$ and $75\pm4\%$ RH. There were 2 replications per treatment in a randomized complete block design. Artificial infestation was as follows: First, plants were inspected to remove any TPW eggs and larvae. Then, 10 plants 40-45 days old were infested once with different numbers of larvae (1, 2, 4, 8, 12, 14 per plant). Plants were inspected 1 day after infestation and larvae replaced if lost. In a 2nd experiment, plants were infested twice with larval levels mentioned above. An uninfested control was sprayed with fenvalerate to keep it TPW free. A second control without insecticide or artificial infestations was also used to compare with treatments. When foliar and fruit injuries occurred in the unsprayed control, these numbers were subtracted from the numbers found in the infested plots.

At harvest, counts of the numbers of leaves and fruits injured were recorded together with the total number of fruits per plant from the upper and lower canopy of the plant. Fruits were graded according to USDA grading standards (Anonymous 1982). In order to reflect market standards, values of the fruit were modified for statistical analysis by multiplying each fruit grade by a number. Numbers of extra large fruit were multiplied by 5, large by 4, medium by 3, small by 2, and very small by 1. Results were also analyzed before multiplication for fruit size. Data were subjected to analysis of variance; treatment means were separated by Duncan's Multiple Range Test at P=0.05.

Regression analysis was used to establish a possible relationship between the number of larvae and the number of leaves and fruit damaged. Data from leaf injuries in the upper plant canopy (Y_u), leaf injuries in the lower canopy (Y_l), number of fruits injured in the upper (F_u), and number of fruits injured in the lower (F_l) canopy were regressed separately on one independent variable: number of larvae per plant (x). The number of fruits injured in the upper (F_u) and lower (F_l) canopy were also regressed on Y_u and Y_l, respectively.

Finally, 2 regression models were used to find a statistical model that related percent yield loss to the number of larvae per plant and to number of foliar injuries. The main objective was to find a simple model for infestation levels which could be used to establish economic injury levels. The regression model used was the form $\hat{y}$ =a+bx and $\hat{y}$= a+bx+cx^2. For the simple linear regression, $\hat{y}$=estimated value of y, a=the y intercept of the regression line, b the regression coefficient and x the sample estimate. For the curvilinear regression, c=the second

regression coefficient preceding the second power of x. Results were compared with the previous work by Poe and Everett (1974), Wolfenbarger et al. (1975) and Wellik et al. (1979).

Second Experiment

To determine the effect of planting date on damage to the tomato fruit by TPW larvae, natural infestations with this insect were studied in those plantings mentioned in Chapter 3. Crops were direct-seeded during October, November and December, 1980 and January and February 1981. Number of injuries per plant and number of tomato fruits damaged and not damaged were recorded for each planting. A total of 20 randomly selected plants was chosen and numbers of damaged tomatoes were compared. Secondly, comparisons in damage estimates obtained from the customary sampling method (6 contiguous plants per row) vs randomly selected plants per row were made. Results were compared by use of relative net precision (RNP=100/RVxCu), for both systems. Thirdly, to determine the effect of pruning laterals on tomato fruit damaged by TPW, laterals from a total of 20 randomly chosen plants (45 days old) were removed and yield was compared to that from 20 unpruned plants. Treatments were replicated 4 times. Analysis of variance and Duncan's Multiple Range Test were used to compare treatments.

Results and Discussion

First Experiment

Single artificial infestation. After a one-time infestation of plants with TPW larvae, the number of fruits damaged in the lower plant

canopy was significantly different from the sprayed control (P=0.05). In the upper canopy average fruit damaged did not differ statistically among infestation levels (Table 28). The number of fruit damaged in the lower canopy when plants were infested with 1 larva was 10.5, 24.5 and 29.5% less than that found at 8, 12, and 14 larvae, respectively (Table 28). In general, damage from 4 larvae per plant and 14 larvae per plant did not differ statistically. Results may indicate that 4 larvae per plant represents the upper practical limit for fruit damage for 'Flora-Dade' tomatoes. The numbers of injuries per fruit may increase with increased larval infestation levels. Once populations reach ca. 4 TPW larvae per plant, multiple injuries to the same fruit may become very common. There is more fruit in the lower than in the upper part of the plant. Because of larval positive geotaxis, larval activity seemed concentrated on the lower plant parts. Consequently, fruit infestation in the lower canopy is higher.

Marketable value of fruits on each canopy was significantly different for the infestation levels when different values were assigned to fruit (Table 29). Values of fruit damaged by 1, 2 and 4 larvae per plant differed from damage by 8, 12 and 14 larvae per plant. Eight, twelve and fourteen larvae caused 1.63, 1.76 and 2.2 times more damage than 1 larvae.

Double artificial infestation. After a double infestation with TPW larvae, the number of fruits damaged in the lower canopy at all levels of infestation was again significantly different from the uninfested control. Tomato fruit damaged in the upper canopy did not differ statistically among infestation levels (Table 30). There were no significant

Table 28. Tomato fruit damaged in the upper and lower plant canopy, after a single artificial infestation with _K. lycopersicella_ larvae on ground tomatoes.

Number Larvae Per Plant	Damaged Fruit Per Plant On*		Total Damage	% Fruit Loss Per Plant
	Upper Canopy	Lower Canopy		
1	0.70 ± 0.92	2.30 ± 1.49^{b}	3.00	10.5
2	1.15 ± 1.26	2.80 ± 1.85^{b}	3.95	10.5
4	1.05 ± 1.23	3.10 ± 2.61^{a}	4.15	9.00
8	0.80 ± 1.15	4.60 ± 2.39^{a}	5.40	19.00
12	1.15 ± 0.93	3.10 ± 2.73^{a}	4.25	35.00
14	1.50 ± 1.67	4.60 ± 3.16^{a}	6.10	40.00
Control**	0.35 ± 0.488	0.90 ± 1.31^{c}	-	-

* Values within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

** Control sprayed weekly with fenvalerate; mean number from treatments was subtracted from infestation that occurred in the untreated control without insecticides.

Table 29. Marketable value for tomato fruit damaged in the lower and upper plant canopy after a single artificial larval infestation of *K. lycopersicella* on ground tomatoes.

Number Larvae Per Plant	Value of Damaged Fruit Per Plant On*		
	Upper Canopy	Lower Canopy	Total Damage
1	1.04^{b**}	7.06^{b}	8.10^{c}
2	1.80^{ab}	5.64^{b}	7.44^{cd}
4	1.35^{ab}	6.63^{b}	7.98^{c}
8	1.65^{ab}	11.57^{a}	13.23^{b}
12	2.17^{a}	12.09^{a}	14.26^{ab}
14	2.71^{a}	15.16^{a}	17.87^{a}
Control	0.55^{c}	3.08^{c}	4.63^{c}

*Average value of damaged fruit based on U.S.D.A. size-grade standards: extra large=5, large=4, medium=3, small=2, very small=1, unit values used in the analysis.

**Values followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 30. Tomato fruit damaged in the lower and upper plant canopy after a double artificial infestation of *K. lycopersicella* larvae on ground tomatoes.

Number Larvae Per Plant	Damaged Fruit Per Plant		Total Damage	% Fruit Loss
	Upper Canopy	Lower Canopy		
1	0.63 ± 0.92^{b}	$2.13 \pm 2.94^{c**}$	2.76	22.45
2	0.50 ± 0.82^{b}	2.73 ± 2.40^{bc}	3.23	27.86
4	0.70 ± 0.95^{b}	3.40 ± 3.72^{abc}	4.10	27.47
8	0.73 ± 1.14^{b}	3.23 ± 4.14^{abc}	3.96	41.28
12	1.10 ± 1.12^{b}	4.46 ± 2.66^{a}	5.56	44.45
14	1.80 ± 1.47^{a}	4.40 ± 2.19^{ab}	6.20	49.00
Control*	0.35 ± 0.48^{c}	0.90 ± 1.31^{d}	1.25	-

* Damaged fruit from an absolute control with insecticide application; results obtained from the treatments were subtracted from the results of the control without insecticides.

** Numbers within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

differences ($P=0.05$) in the lower canopy observed between 1 larva infesting the plant and the 2-14 larval infestation levels. Infestation with 14 larvae per plant resulted in 2.24 times more damage than 1 larva. Marketable values of fruits on each canopy were significantly different from the control (Table 31). Values were not significantly different among the treatment levels.

In explanation of these results, successive generations of TPW may increase damage per fruit. Since the damage index is the number of fruit damaged per plant, the number of injuries produced per fruit is not accounted for. Another explanation could be that competition among larvae may displace the second larval infestation to the foliar canopy, reducing injury to the fruit.

Relationship Between Leaf and Fruit Injury and Larval Infestation Levels

Single infestation. Factors that relate to the estimation of larval presence were examined: the validity of using leaf injury and the fruit injured respective to the number of larvae per plant, and the use of foliar injury to detect fruit damage. A curvilinear and linear regression equation indicating leaf and fruit injury expressed in function of the number of larvae per plant as an independent variable is shown in Figures 11-12. The relationship between leaf injuries found in the lower canopy (Y_1) and the number of larvae (x) per plant was best described by the following highly significant ($P<0.009$) linear regression ($y=2.3 + 0.41x$, $r^2=0.511$) (Fig. 11). The relationship between fruit injured in the lower canopy (F_1) and the number of larvae

Table 31. Marketable value for the tomato fruit damaged in the lower and upper plant canopy after a double infestation of _K._ _lycopersicella_ on ground tomatoes.

Number Larvae Per Plant	Value of Damaged Fruit Per Plant On*		
	Upper Canopy	Lower Canopy	Total Damage
1	1.22^{ab**}	5.60^{ab}	6.83^{ab}
2	1.34^{ab}	7.78^{ab}	9.13^{ab}
4	1.33^{ab}	8.39^{ab}	9.73^{ab}
8	1.17^{ab}	8.93^{ab}	10.11^{ab}
12	2.32^{ab}	11.11^{a}	13.43^{a}
14	3.06^{a}	10.23^{a}	13.30^{a}
Control	0.55^{b}	3.08^{b}	3.64^{b}

*Average damaged fruit as estimated from commercial value, extra large fruit=5, large=4, medium=3, small=2, very small=1, market values used in this analysis.

**Values followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Figure 11. Relationship between number of tomato pinworm larvae per plant and number of injured fruits and leaves in the lower plant canopy by a single artificial infestation with TPW harvae. Homestead, Florida, 1980-1981.

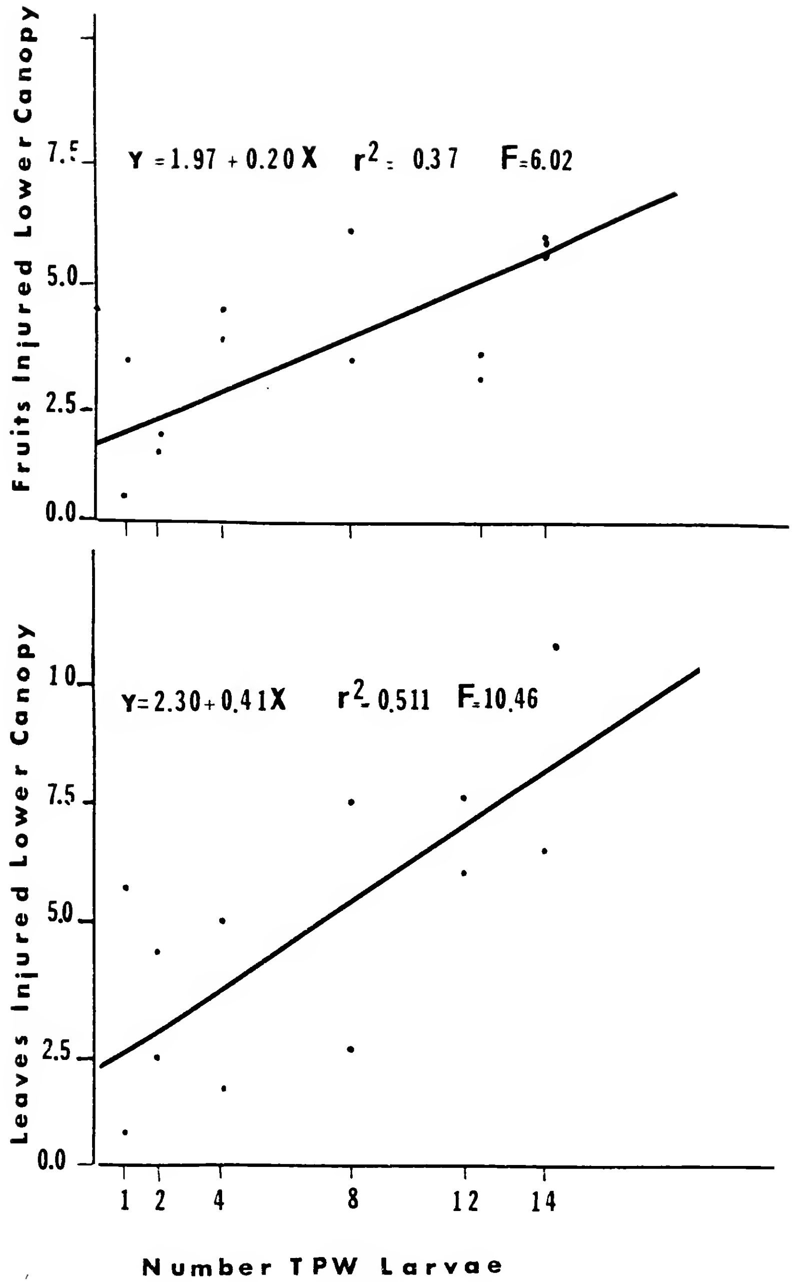
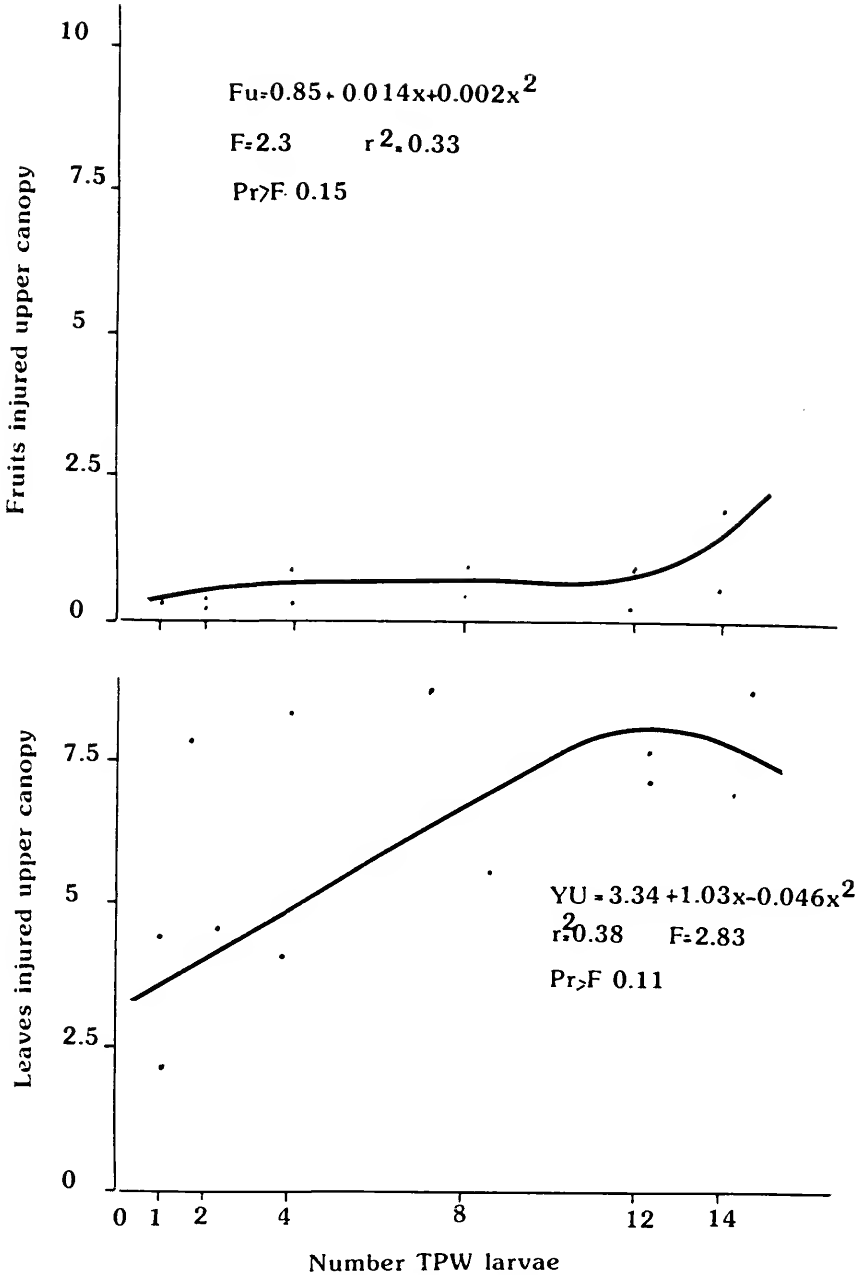

Fruits Injured Lower Canopy
Y = 1.97 + 0.20 X
r2 = 0.37
F=6.02
7.5
5.0
2.5
0.0
Leaves Injured Lower Canopy
Y= 2.30+ 0.41X
r2 = 0.511
F=10.46
10
7.5
5.0
2.5
0.0
1
2
4
8
12
14
Number TPW Larvae

Figure. 12. Relationship between number of tomato pinworm larvae per plant and number of injured fruits and leaves in the upper plant canopy by a single infestation of TPW larvae. Homestead, Florida, 1980-81.



10
7.5
5
2.5
0
Fruits injured upper canopy
Fu=0.85+0.014x+0.002x2
F=2.3
r2=0.33
Pr>F 0.15
7.5
5
2.5
0
Leaves injured upper canopy
YU=3.34+1.03x-0.046x2
r2=0.38
F=2.83
Pr>F 0.11
0
1
2
4
8
12
14
Number TPW larvae

(x) was best expressed by the following significant ($P<0.03$) linear regression. The r^2 value ($r^2=0.37$) was less than intermediate. The correlation coefficients for the lower canopy were intermediate, indicating that 51-37% of the variation in foliar and fruit injuries was due to larval numbers infesting plants.

When data from the upper canopy were regressed against the number of larvae per plant, curvilinear regression had a better fit than linear regression. There was no significant relationship found between injuries in the upper canopy (Y_u) and number of larvae (x) infesting the plant (Fig. 12). Again, no significant relationship was found between injured fruits in the upper canopy (F_u) and the number of larvae per plant. The lack of significant relationship between larval numbers and TPW injuries in the upper canopy indicate that upper canopy counts can not explain number of larvae present in the plant at TR_2 stage.

The relationship between fruits injured in the lower canopy (F_1) and foliar injuries in the lower canopy (Y_1) was best expressed by a significant ($P=0.024$) quadratic equation $F_1 =1.09 + 0.46Y_1-0.02Y_1^2$ and $r^2=0.56$. (Fig. 13). F_1 began to decrease at a level of about 7.5 injuries per plant. This may be an artifact, or it may be that beyond this level of larval infestation of leaves, multiple injuries to fruit may be more common than infestation of undamaged ones. Regression analysis of numbers of fruit injured in the upper canopy and foliar injuries in the same plant part did not indicate a significant relationship (Fig. 14). Also, regression of fruit injured on lower canopy and the total plant injuries was not significant. Therefore, TPW sampling by scouts is probably best done in the lower plant canopy.

Figure 13. Relationship between number of leaves injured in upper and lower canopy and number of fruits injured in upper and lower canopy by a single artificial infestation with TPW larvae. Homestead, Florida, 1980-81.

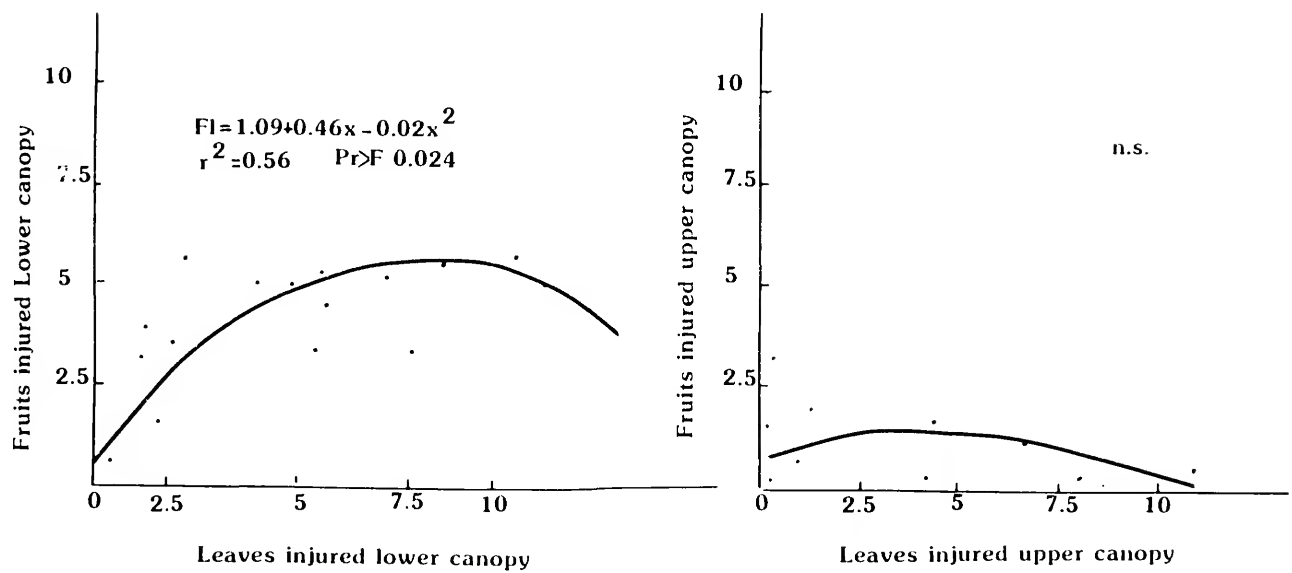
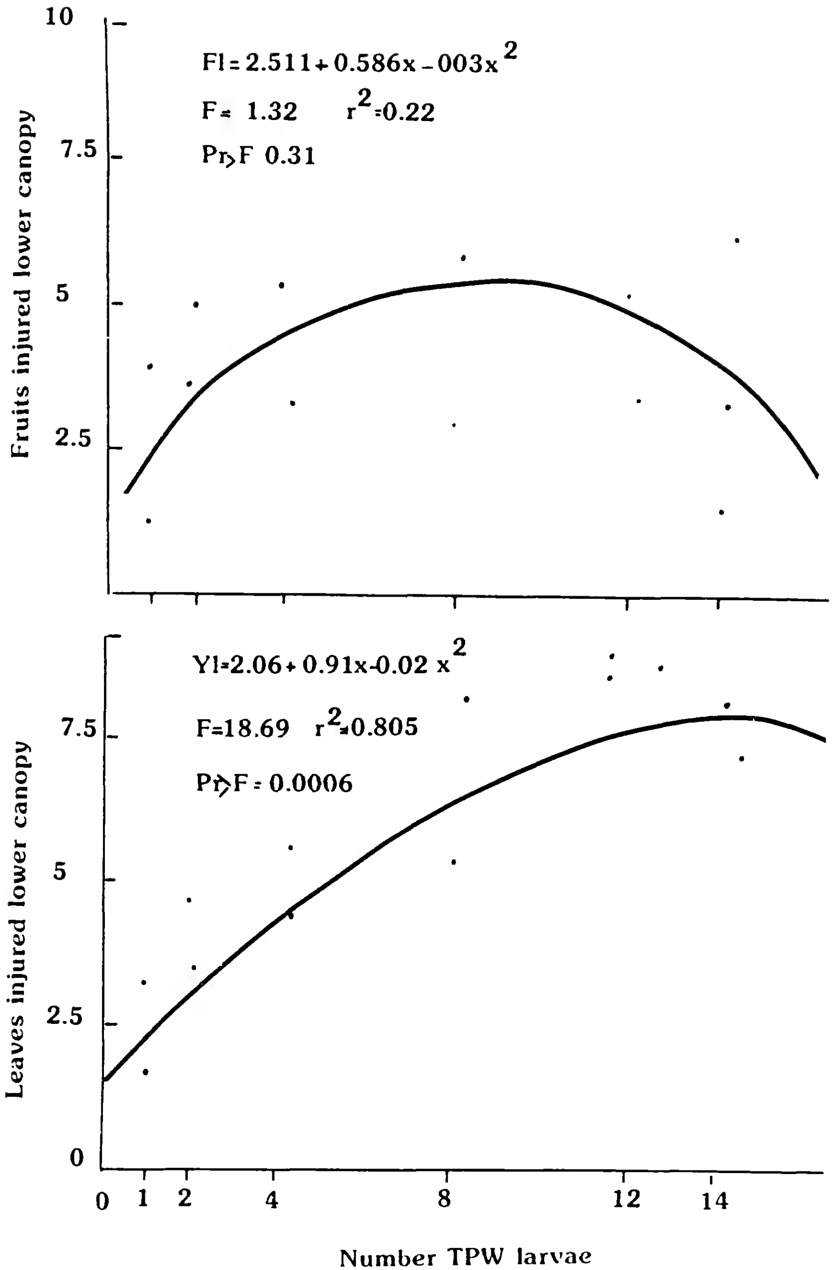

FI=1.09+0.46x-0.02x2
r2=0.56 Pr>F 0.024
Fruits injured Lower canopy
Leaves injured lower canopy
10
7.5
5
2.5
0
n.s.
Fruits injured upper canopy
Leaves injured upper canopy

Figure 14. Relationship between number of larvae per plant and number of injured fruits and leaves (upper and lower canopy) after a double artificial infestation with TPW larvae. Homestead, Florida, 1980-81.



Fl = 2.511 + 0.586x - 003x 2
F = 1.32 r 2 =0.22
Pr>F 0.31
Fruits injured lower canopy
10
7.5
5
2.5
Yl=2.06 + 0.91x-0.02 x 2
F=18.69 r 2 =0.805
Pr>F = 0.0006
Leaves injured lower canopy
0
0 1 2 4 8 12 14
Number TPW larvae

Relationship Between Leaf, Fruit Injury and Larval Infestation Levels

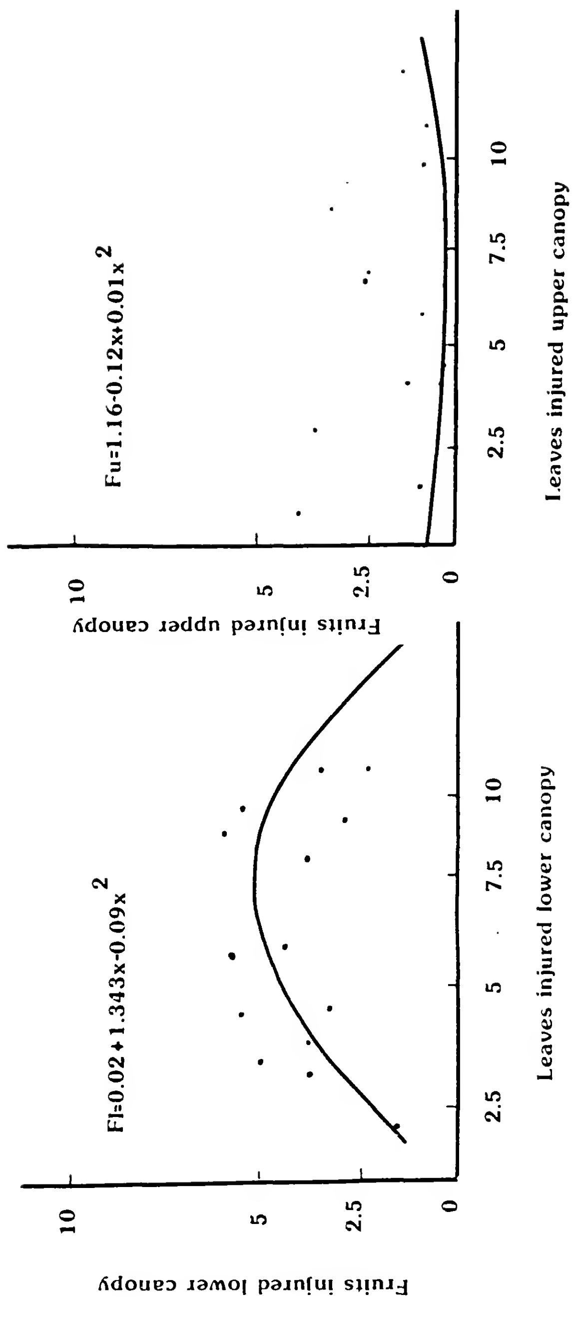
Double infestation. The relationship between leaves injured in the lower canopy (Y_l) and number of TPW larvae (x) was best fitted to the highly significant (P=0.0006) curvilinear regression, $Y_l=2.06+0.91x - 0.02x^2$, F=18.69, $r^2=0.805$ (Fig. 14). The relationship between fruit injured in the lower canopy (F_l) and the number of larvae (x) was not significant (F=1.32, P=0.31). When data from upper canopy were regressed against number of larvae (two-time infestation) per plant, there was no significant regression found between injuries in the upper canopy (Y_u) and number of larvae (Fig. 14). No significant relationship was found between injured fruits in the upper canopy (F_u) and number of larvae per plant.

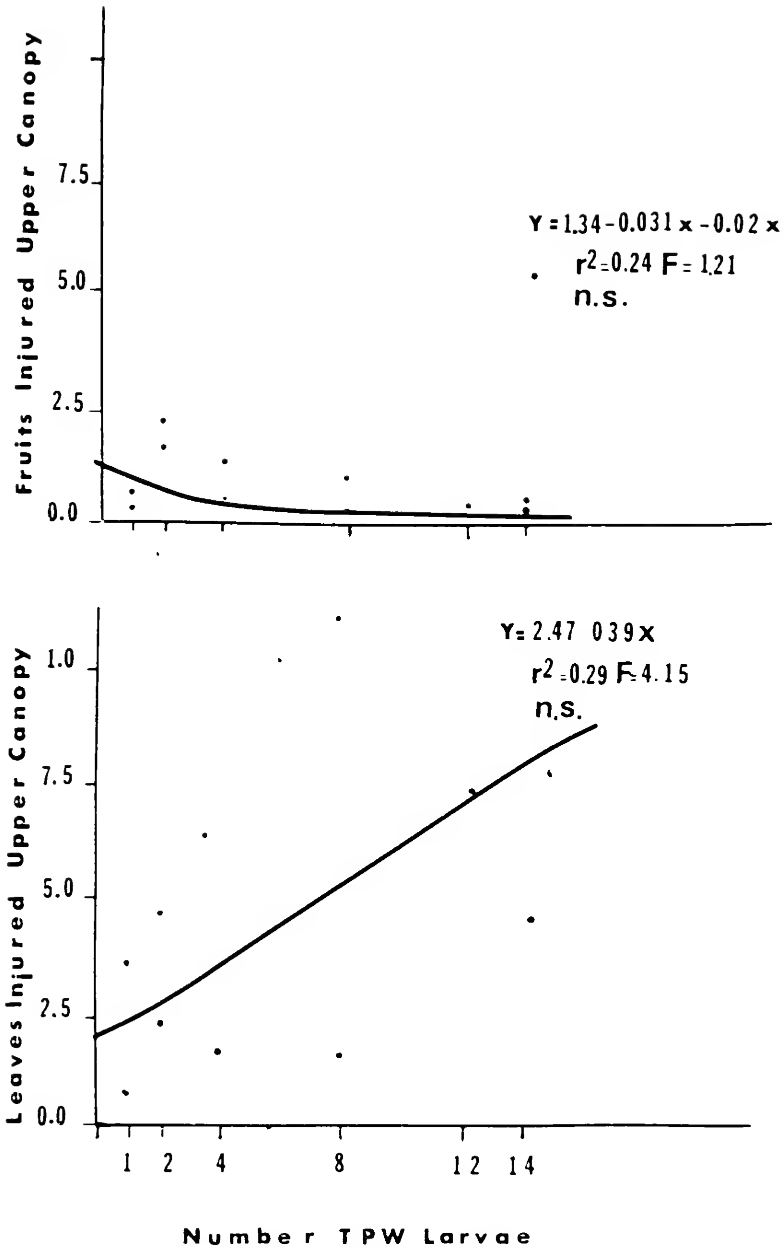
The relationship between fruits injured in the lower canopy and foliar injuries in the lower canopy was not significant, F=1.21, P=0.341, $r^2=0.212$ (Fig. 15). The regression analysis between fruits injured in the upper canopy (F_u) and leaves injured in the upper canopy (Y_u) was not significant, F=0.98, P=0.33, $r^2=0.04$ (Fig. 15). The reasons why there was no relationship between fruits injured and foliar injuries caused by a double TPW infestation may be due to an artifact, but it may be that a double TPW larval infestation causes more injuries to the same fruit, which will result in no increment of the total fruit damaged per plant.

Yield Loss vs Density of TPW Larvae in Tomatoes

The second order model $y=a+bx+cx^2$, (y=percent of yield loss, x= number of TPW larvae per plant), was fitted to the data on mean percent

Figure 15. Relationship between number of leaves injured in upper and lower canopy and number of fruits injured in upper and lower canopy by a double artificial infestation with TPW larvae. Homestead, Florida, 1980-81.


Fu=1.16-0.12x+0.01x2
Fruits injured upper canopy
Leaves injured upper canopy
0
2.5
5
7.5
10
Fl=0.02+1.343x-0.09x2
Fruits injured lower canopy
Leaves injured lower canopy



Fruits Injured Upper Canopy
7.5
5.0
2.5
0.0
Y = 1.34 - 0.031 x - 0.02 x²
r² = 0.24 F = 1.21
n.s.
Leaves Injured Upper Canopy
1.0
7.5
5.0
2.5
0.0
Y= 2.47 039X
r² = 0.29 F= 4.15
n.s.
1 2 4 8 12 14
Number TPW Larvae

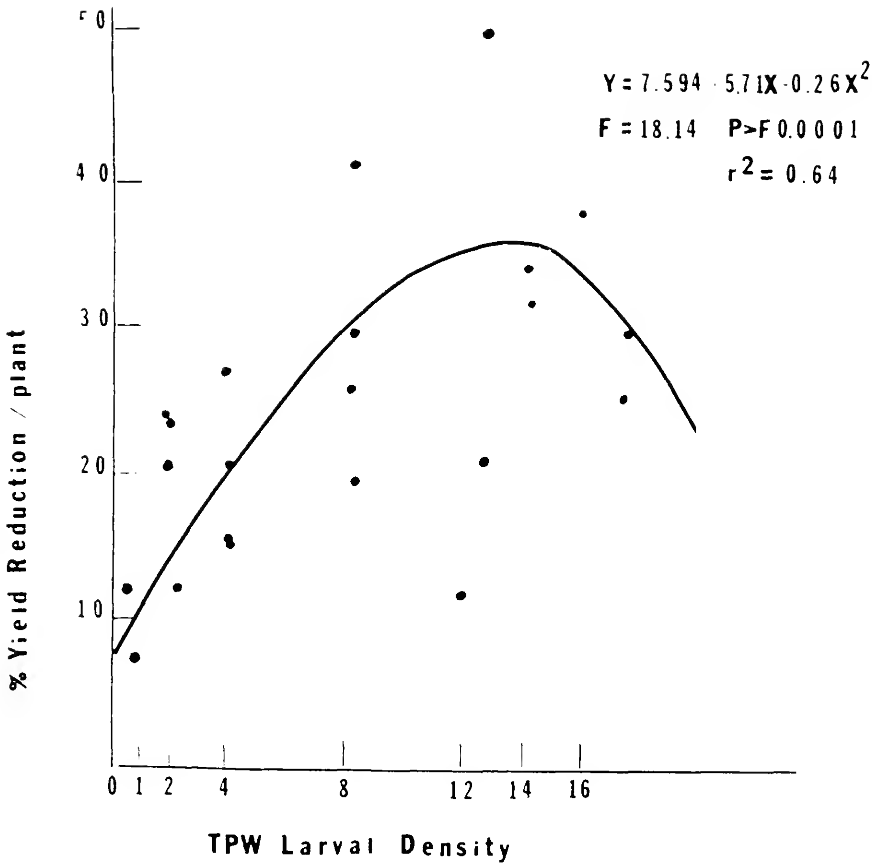
yield losses for 3 tomato plantings attacked by TPW. The relationship was highly significant, P=0.001 and had an intermediate r^2 value of 0.64 (Fig. 16). The coefficient estimates b and c were significant. A positive increment in yield losses was observed until 12 larvae were infesting the plant; in contrast, beyond this infestation level, the percentage of yield losses decreased.

Yield Losses vs Number of Plant Injuries

A significant curvilinear ($y=8.76+4.21x - 0.14x^2$) regression was found when mean percent yield losses combined for 3 plantings were plotted vs TPW injuries per plant (P=0.001) (Fig. 17) for numbers of foliar injuries up to 27 per plant. Regression analysis indicated a positive relationship between yield losses and 10-15 injuries per plant. The relationship turned negative when more than 15 injuries are found per plant. Based on r^2 value, the fitness of the model was intermediate (r^2=0.608), but higher than that found with a simple linear regression model (r^2=0.322).

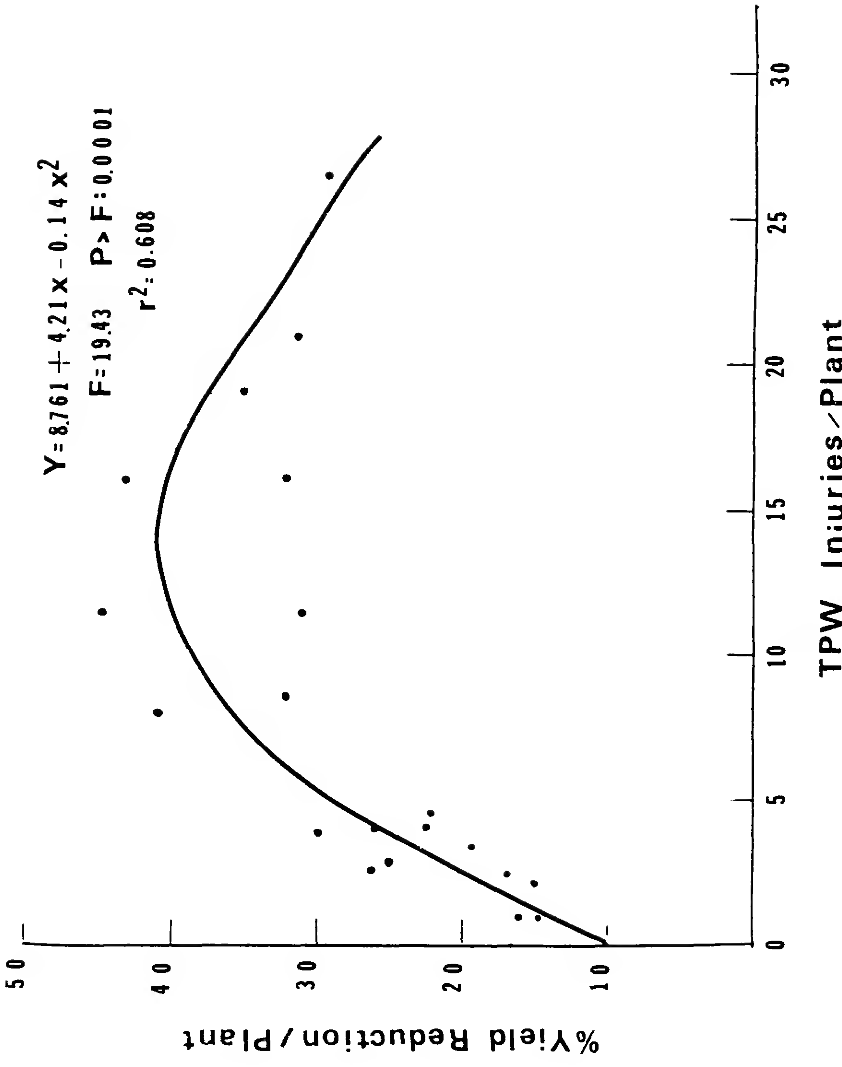
Actual yield losses may vary, depending on time of planting and southern Florida environmental conditions. A more robust model relating density and yield losses should be considered with lower larval infestation levels per plant. The models developed here provide valuable information on the TPW-plant interactions. TPW larvae may bore into the fruit for different reasons, yet high attraction to the fruit was not found by Swank (1937). Thus, larval density, contact between injured leaves and fruits, or positive geotaxis observed when the larva suspends itself by the thread produced from the spineret, may account for the fruit damage especially on the lower canopy.

Figure 16. Regression of percent of yield reduction against infestation densities per plant of tomato pinworm larvae.



50
40
30
20
10
Y = 7.594 · 5.71X - 0.26X²
F = 18.14 P>F 0.0001
r² = 0.64
% Yield Reduction / plant
0 1 2 4 8 12 14 16
TPW Larval Density

Figure 17. Regression of percent yield reduction of tomato fruit against TPW number of foliar injuries per plant.



Y= 8.761 + 4.21 x − 0.14 x²
F=19.43   P> F: 0.0001
r²: 0.608
%Yield Reduction / Plant
50
40
30
20
10
TPW Injuries/Plant
0
5
10
15
20
25
30

Estimates of economic injury levels for TPW larvae may be made by inspecting the equations describing the relationship between fruit damage and larval density. The high market price of the tomato crop and cost of controlling TPW larvae indicate again that infestation levels lower than 1 larva per plant should be used. The minimum economic injury level damage determined for green cloverworm in soybeans by Stone and Pedigo (1972) and modified by Hopkins et al. (1982) and Hall and Teetes (1982) is defined as EIL= $\sqrt{(C/P)/b}$, where c=total cost of controlling the insect pest/ha, p=price or market value of the crop per ha, and b=the regression value from the regression equation used. Gain threshold (Stone and Pedigo 1982) = (control cost/market value)x 100. For example, if the cost of controlling TPW is $50 per ha, and the market crop value of tomato is $6629.5/ha, the percent gain threshold would be 0.0075x100=0.754. The economic injury level for an infestation of TPW could be calculated by using the regression coefficient (b=1.67) from the linear regression equation $y=15.08 + 1.67\ x$; $r^2=0.45$; $F=17.72$ $P>F=0.004$: EIL= $\sqrt{0.75/1.67}$ = 0.67 tomato pinworm larvae per plant. Similarly, the economic injury level based on the population index (number of injuries per plant) can be calculatedusing the regression coefficient (b=1.07) from the linear regression equation $y=16.82 + 1.07x$; $r^2=0.32$; EIL= $\sqrt{0.75/0.07}$ = 0.83 tomato pinworm larval injuries per plant.

There are constraints for these economic injury levels. They are based on results from one phenological stage (TR_2). Therefore, it is not known if they can be used for earlier stages (TV_1 - TR_1). Planting time will also affect these results as demonstrated in the next experiment.

Second Experiment

Effect of planting time on yield. Earliest plantings (October, 1980) had the lowest TPW fruit damage (Table 32). Significant differences in number of fruit damaged per plant were found between those crops planted during October-December and crops planted during January-February. Largest infestations occurred in the latest planting (February, 1981). The amount of TPW damage in southern Florida depends on planting date with the greatest threat during the winter-spring crops. Planting time might be considered as part of an integrated control program for TPW. These results call for further research on economic injury levels related to planting time. For instance, TPW population peaks occur during March-May (Chapter 7). At this time, those crops planted during the fall have already been harvested or are in the second reproductive stage (TR_2). The use of an earlier planting date will be a common sense approach to pest avoidance.

Effect of plant pruning and number of plants per row related to fruit damage. Pruning plants had no effect on fruit damage (Table 33). Trends in the data suggest that further studies should be done with more levels of pruning in the experimental design. Differences in relative net precision using 6 contiguous plants/row opposed to random plants per row did not show any statistical difference (Table 34). Number of total fruits per row in those plants selected at random was slightly higher but did not lead to better RNP values. Therefore either method can be used for selecting tomato plant for TPW assessment.

Table 32. Effect of planting time on fruit injured by _K. lycopersicella_ larvae to ground tomatoes, cv 'Flora-Dade' during 1981.

Planting Time	Total Fruit Damaged/Plant*	Average Leaf Injuries/Plant
Oct. 30, 1980	0.667[b]**	0.6
Nov. 25, 1980	3.154[b]	2.52
Dec. 30, 1980	5.11[b]	8.35
Jan. 30, 1981	13.35[a]	10.80
Feb. 28, 1981	16.95[a]	12.57

*Plantings without insecticide protection 20 days after emergence.

**Values followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Table 33. Differences in cost and relative net precision between sampling 6 plants per row and 1 random plant per row.

Plants Per Row	N	Injuries Per Plant	Time**	RNV	Total Fruit/Plant
6 plants	18	$1.27 \pm 0.47^{\dagger}$	1.59	15	19.361
1 plant	18	1.33 ± 0.40	2.38	12.34	25.08

*Relative net precision = $\dfrac{100}{RV \times Cs}$

**Time expressed in minutes expended in detecting foliar injuries and walking from 1 plant to another.

†Numbers followed by the same letter are not significantly different according to Student's t-test (P=0.05).

Table 34. Differences in mean fruit injured by _K. lycopersicella_ in pruned and not pruned tomato plants.

Treatment	Total Fruits/Plant	Injured Fruits	% Injured Fruits
Without pruning	26	6.90[a]	26.95
Pruned	28	4.70	17.09

[a] Mean values followed by the same letter are not significantly different according to t-test (P=0.05).

Conclusions and General Discussion

The information generated in this study is useful to demonstrate the complex effect of different TPW densities on tomato plants. First, a single infestation of 1, 2, 4, 8, 12 and 14 larvae per plant resulted in a 10.50 - 40% fruit loss. The result contrasted with 22.5 - 49% fruit loss obtained when larval levels were doubled. This demonstrated that only one generation of TPW is necessary to cause severe (40%) losses, and also, data suggest that in spite of low larval levels (1 larva/plant), yield losses are twice as much if two generations occur.

Second, regression analysis between number of fruit injured and number of TPW larvae demonstrated the importance of plant stratum selection for sampling TPW. Generally, the number of TPW larvae (x) was better related (r^2=0.51) to the number of leaves injured in the lower canopy than to the number of leaves injured in the upper canopy (r^2=0.38). Also, number of leaves injured in the lower canopy (x) and fruits injured in the lower canopy were better related (r^2=0.56) than leaves and fruits in the upper canopy. These results were expected because higher infestations occurred on middle and lower canopies where most of the tomato fruit is located.

The relationship between number of TPW larvae per plant (x) and percent yield loss was intermediate (r^2=0.64). Data from a simple linear regression (r^2=0.45) was used to determine EIL. EIL for TPW was 0.67 larvae per plant. The relationship between number of injuries per plant (x) and percent yield losses was fitted to a significant curvilinear regression ($y=8.76 + 4.21x - 0.14x^2$). The fitness of the model was intermediate (r^2=0.608). Data from a simple linear

regression (r^2=0.322) was used to determine EIL based on the damage index. The EIL was 0.83 TPW larval injuries per plant.

There are, however, some constraints for these economic injury levels. The EIL is based on results from one phenological stage (TR_2); therefore, it is not known if they apply to other stages (TV_1 - TR_1). Planting time will affect these results. Results concerning effect of planting time suggest once again that the southern Florida farmers should avoid planting during the later winter season because of higher TPW population peaks during March-May.

CHAPTER VI
ADULT DISPERSION AND COLONIZATION OF TOMATO FIELDS BY THE TOMATO PINWORM

Introduction

Dispersion and field colonization should be among the first factors considered with regard to insect distributional patterns (Price 1976). Knowledge of spatial patterns is considered basic to design of appropriate sampling plans and provides insight into the biology of the species in question (Shepard and Carner 1976).

Colonization patterns of members of the family Gelechiidae have been studied mainly for the pink bollworm (*Pectinophora gossypiella* Saunders). The Gelechiidae are considered weak fliers whose patterns of dispersion are strongly influenced by wind, patchiness of the environment, and also voltinism (Shelton and Wyman 1979a,b; Kaae et al. 1977; Stern 1979).

Little has been done on the study of the factors affecting patterns of dispersion of the TPW in commercial fields. It has been observed that a common feature of TPW is its aggregation at the edges of fields (V.H. Waddill, personal communication). The purpose of this study was to determine the colonization pattern of TPW and to define the effect of edges and hedgerows on the insect's distribution.

Materials and Methods

Dispersal of TPW Male Moths in the Field

This study was conducted during February through May, 1980, and May-June, 1981, in order to determine short range pinworm dispersal within the field. TPW was monitored by placing Pherecon 1c® sticky traps 60 cm above the ground and baiting them with sex attractant (95.3%-(E)-4-tridecen-1-01 Acetate; 4.5%-(Z)-4-Tridecen-1-01 Acetate) (personal communication, R. Heath, USDA, Gainesville, Fla.). In all 0.5-3 ha tomato fields of this study, three traps were placed in each of the major compass directions (north, west, east, and south); the trap lines and distances between them were 12, 60, and 300 m from the center of the first field, and 12, 30, and 48 m for the remaining ones. Trapped TPW male moths were recorded and removed daily from each trap during February-March and April-May. This survey determined male moth activity from the border to the center of the field.

Colonization Pattern of Tomato Fields by TPW

Tomato pinworm egg distribution can be considered an indicator of female moth activity in a field. Because of low TPW larval motility within the fields, immature stages were also taken as an index of population dispersion and colonization in the tomato fields. Four fields ca. 1-3 ha located near Homestead, Florida were the study sites. The fields had been under cultivation for several years in a corn- tomatoes- bean- or squash rotation. No insecticides were applied during the

sampling time. Three sampling sites were located at rows 0, 30, and 120 m from the edge to the center of the field. Twenty randomly selected plants from each row site were selected weekly, until the farming practices (tillage, discing, or insecticide application) interfered with sampling. The sampling unit used was larval injuries per plant. Data from each field were analyzed by analysis of variance and means from each site were separated by Duncan's Multiple Range Test (P=0.05).

Effect of Edges and Hedgerows of TPW Distribution

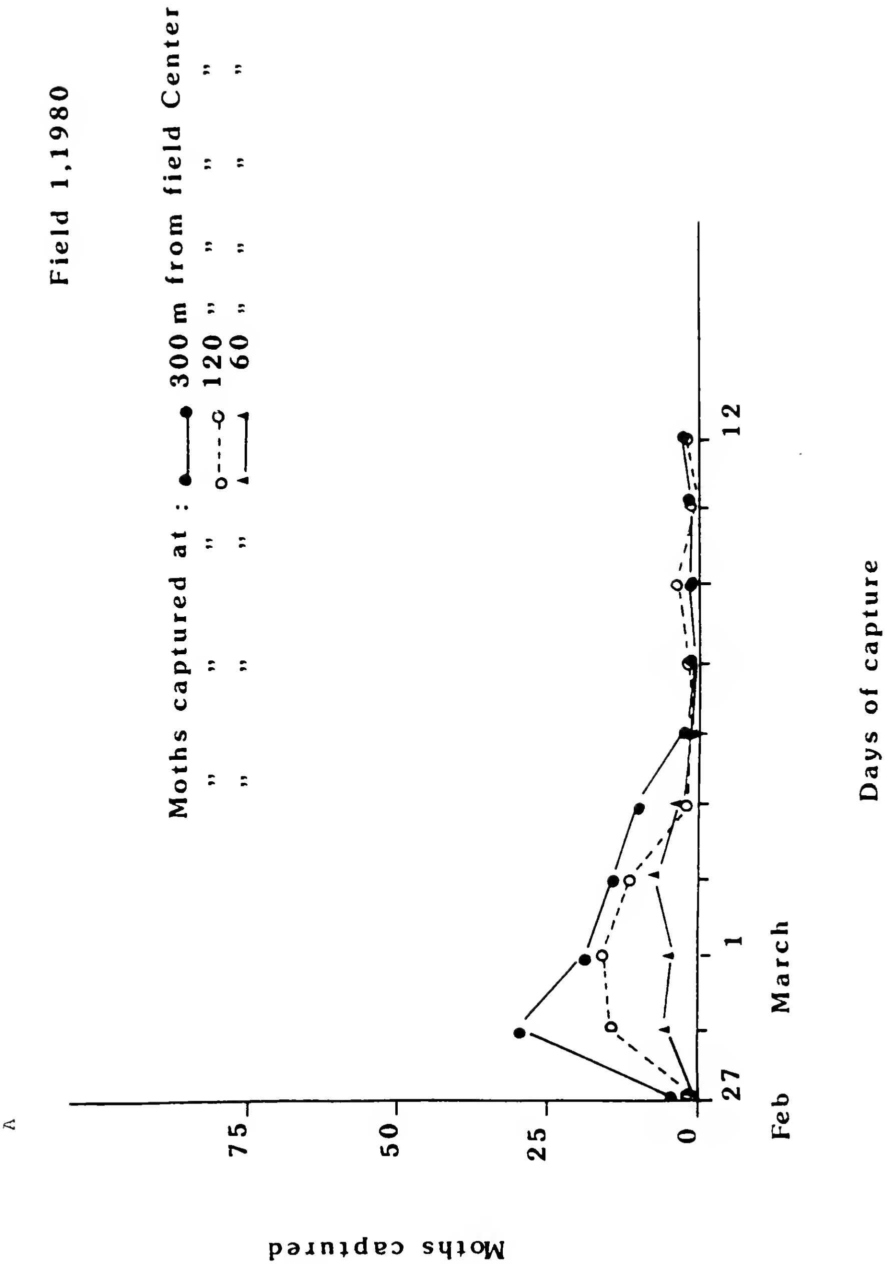
Three post-harvested tomato fields abandoned after the 2nd commercial harvest were sampled on May 4-22, 1981. Field sizes fluctuated between 0.88-1.32 ha. These were divided into (ca. 1100 m^2) quadrats. Two middle leaves per plant were taken as the sampling unit from 20 randomly selected plants per quadrat, to detect the presence of TPW larval injury. The first field was bordered to the northwest by mango trees (*Mangifera indica* L.), to the north and northeast by tomatoes, and to the south by a main road and grassland. The second field was bordered to the northwest by grassland, to the south by a hedgerow or windfall of *Casuarina equisetifolia* Forst, and to the east and north by a corn field and a main road, respectively. The third field was separated to the north and south by a windfall of *C. equisetifolia*, and bordered to the east by a sweet potato (*Ipomoea batata* (L.)) field, and to the west by a main road and grassland. For each field, mean numbers of TPW foliar injuries were averaged per quadrat. Each quadrat was considered a treatment. Differences among quadrats were defined by use of analysis of variance and statistical differences were determined by use of Duncan's Multiple Range Test (P=0.05).

Results and Discussion

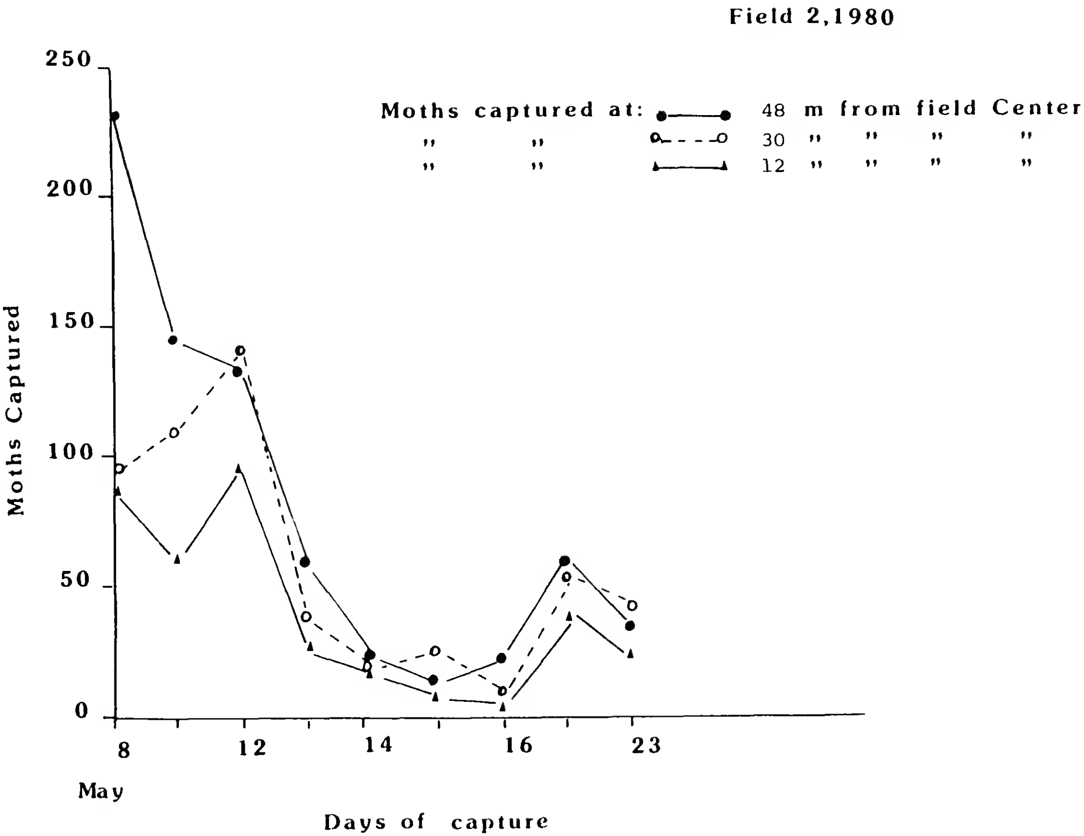
Dispersal of TPW Male Moths in the Field

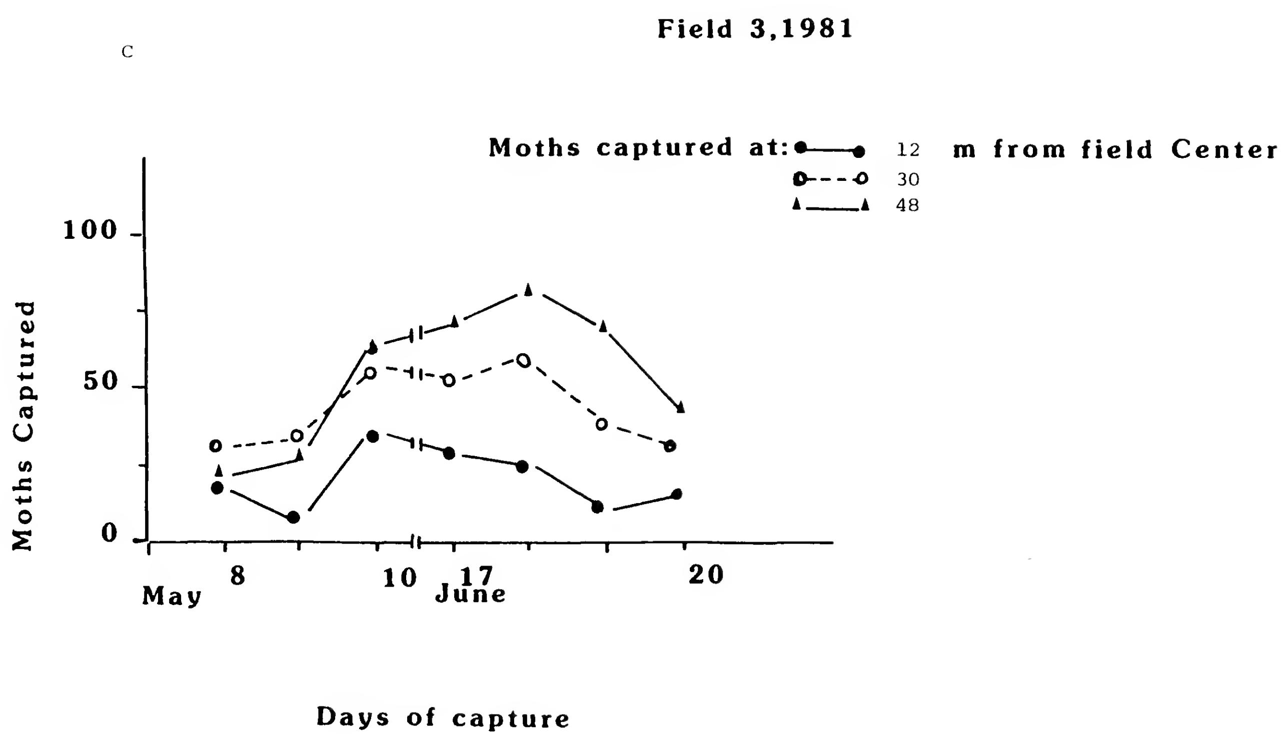
The results presented in Fig. 18 reveal a pattern of *K. lycopersicella* male distribution which indicate that males are mainly found in the borders of the field. Data indicate male distribution only, although I hypothesize (without evidence) that female distribution follows the same pattern. Fewer males (10-50) were captured during the early part of the tomato growing season, February-March, than later, May-June (75-395). The data probably reflect several successive generations being produced in the field. During February-March, 1980, males were more abundant (62%) in traps located farther from the center of the field (300 m) than in those located closer (12-26%). The same negative trend toward the center of the field (17-42%) was observed during May-June, 1980-81. The predominant wind direction during February-March was NE, and the proportion of moths captured corresponded to those traps oriented N, W, E, and S, respectively. The behavior of TPW males indicated that there may be a dispersal tendency toward areas close to the edges of the field. If the trapped moths were not part of the natal population, data may indicate that TPW is a good colonizer which concentrates mainly in the field edges, having a slower dispersion within the field. Perhaps the migratory TPW population initiates a fast field colonization at the borders, but later generations colonize the field slower, since there is no need to cover long distances inside the tomato field if food is available.

Figure 18. Abundance of tomato pinworm male moths at three different field sites. A) Field 1, 1980; B) Field 2, 1980; C) Field 3, 1981. Mean number of moths at each site corresponds to the average from 4 pheromone traps in north, south, west, and east directions, Homestead, Florida, 1980-1981.


A
Field 1,1980
Moths captured at : 300 m from field Center
" " " 120 " " " "
" " " 60 " " " "
Moths captured
0
25
50
75
Feb 27
March 1
12
Days of capture

B

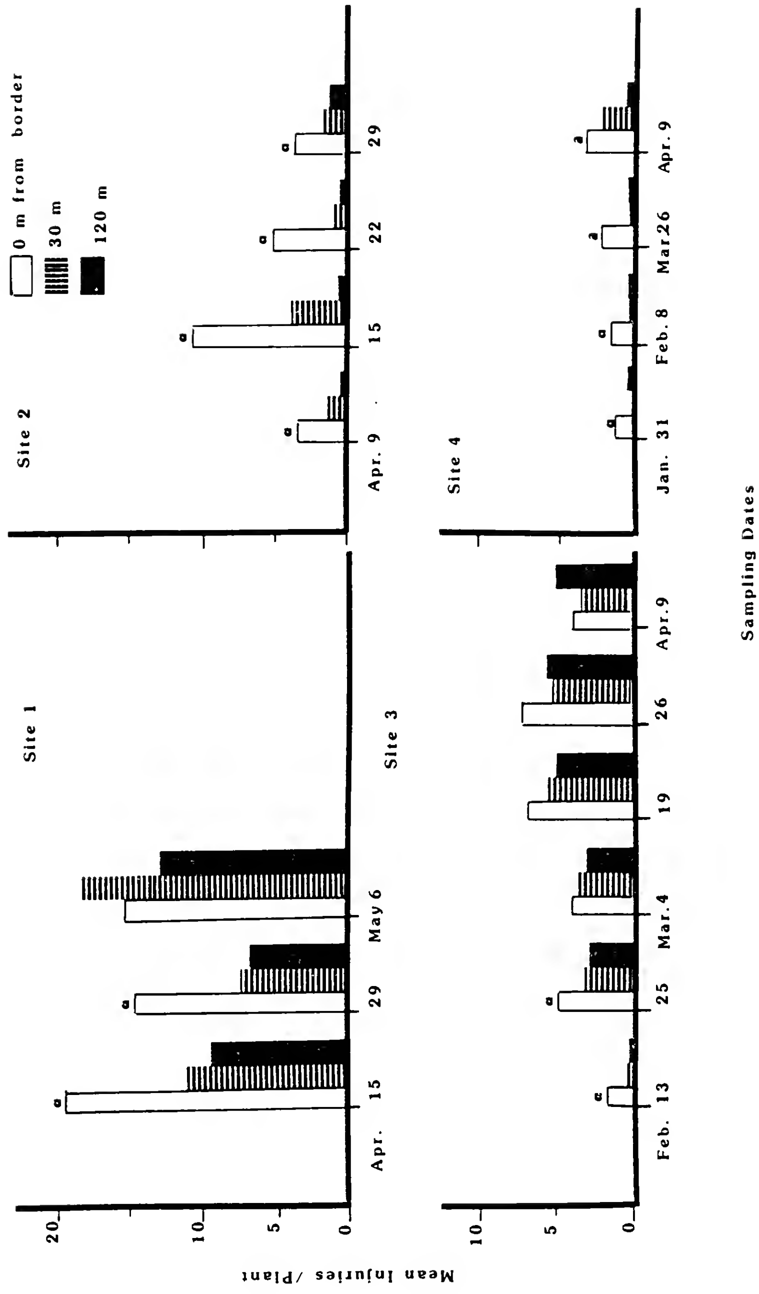

Field 2,1980
Moths captured at: 48 m from field Center
" " 30 " " " "
" " 12 " " " "
250
200
150
100
50
0
Moths Captured
8
12
14
16
23
May
Days of capture


Field 3,1981
C
Moths captured at:
12
30
48
m from field Center
100
50
0
Moths Captured
May
8
10
17
June
20
Days of capture

Colonization of Tomato Fields by TPW

The results obtained in this experiment (Fig. 19) demonstrated statistical differences (P=0.05) in number of injuries per plant during 12 of the 17 sampling dates among the border and rows located 30 and 120 m from the edges of the 4 fields sampled. The first field, sampled from January-April, had a lower infestation (less than 5 injuries/plant) than the others. The border of the field had the highest counts (15-19) and did not increase sharply toward inner areas until April, 1980. The second field, sampled in April, had higher counts (4-10 injuries/plant) at the border, than at 30 m (1-4 injuries) or at 120 m (0.5-1 injuries) from the border. The third field, sampled from February-April, showed a larger increment toward the inner parts of the field during the first 2 weeks of sampling and remained as high as the border for the subsequent sampling dates. However, the infestation obtained at the border (1.5-3 injuries/plant) was significantly higher than that obtained in the inner areas (0-2.5). There are several factors that may influence these patterns, such as plant growth and temperature. Also, these data may reflect different behavioral characteristics of different TPW generations. I hypothesize (again without evidence) that moths which colonize the field settle on field edges for several reasons (wind drift, etc.). The next generations produced on each field move inside the field depending on depletion of resources by previous larvae. The faster or

Figure 19. Mean number of tomato pinworm larval injuries occurring in 4 commercial fields at 0, 30, and 120 m from the field border. Bars with the letter "a" denote statistical differences at 0.05% difference level for a particular date.


Site 1
Site 2
Site 3
Site 4
0 m from border
30 m
120 m
Apr. 15
29
May 6
Apr. 9
15
22
29
Feb. 13
25
Mar. 4
19
26
Apr. 9
Jan. 31
Feb. 8
Mar. 26
Apr. 9
20
10
5
0
Mean Injuries /Plant
Sampling Dates

slower colonization of tomato fields will reflect the density of the 1st TPW generation.

Experiment 2

The combination of data from the three fields sampled during 1981 enabled a fair analysis to be made of the importance of edgerows and hedges in the process of any TPW infestation (Table 35, Fig. 20). There were three broad edge categories: 1) hedgerows or windfalls, 2) road or pastures adjacent, and 3) edge surrounded by the same crop or other crops (corn, sweet potato). In general, TPW larvae showed maximum density near windfalls. Also, density increased in different parts of the fields surrounded by grassland and separated by a road. Two fields had the highest population at the eastern edge of the field. Hedgerows had the highest infestation (3.2-6.25 injuries/plant) compared to road edges (1.20-4.10) and other crops or tomatoes as edge (0.33-4.15). Edges surrounded by pastures had a similar infestation range (4.47-5.82) as those surrounded by hedgerows.

The presence of hedges around fields probably increases the chances of cumulative infestation by TPW. Because of lack of sheltering vegetation, edges surrounded by pastures and roads are probably the entrance for insects from neighboring fields. Lewis (1969) suggested, also, that the pattern followed by flying insects depends on a process of uniform delivery followed by differential removal from the air above different parts of the field. Since TPW larvae are slow movers within the field, the measure of immature insect stages could be taken as a result of adult dispersal. The results in this study again support the idea of

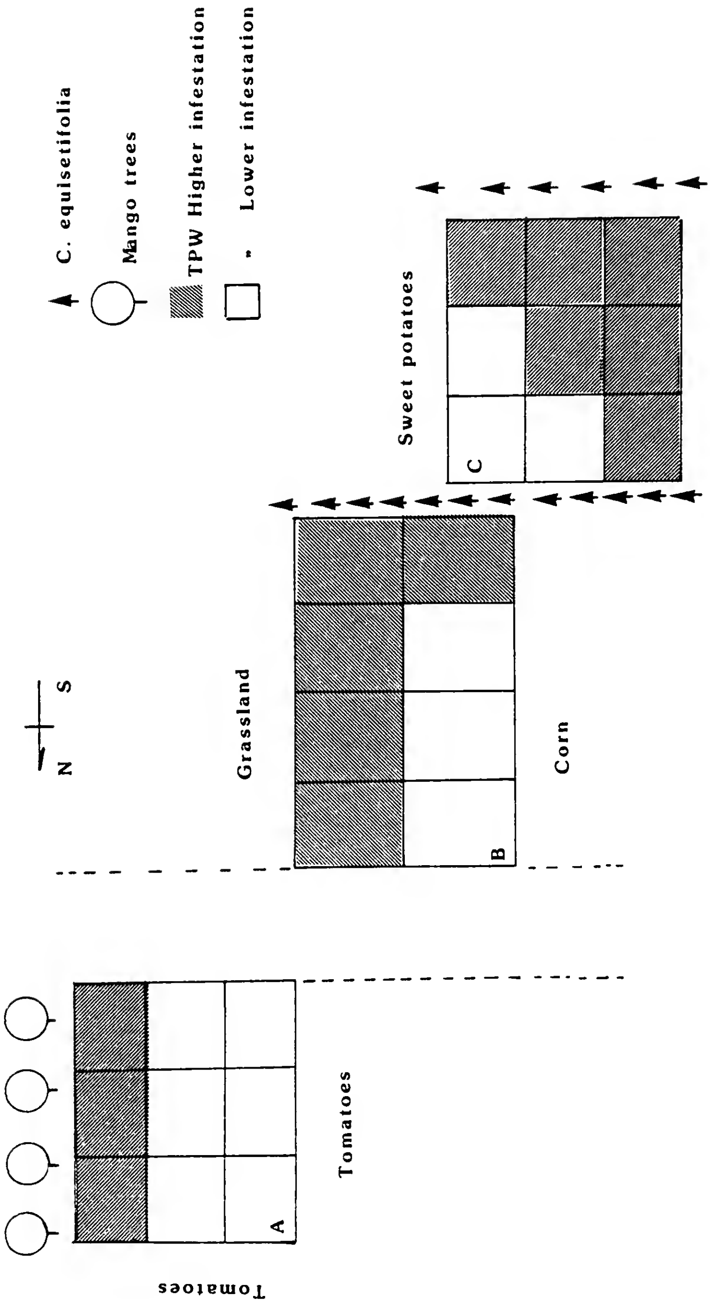
Table 35. Effect of hedges and edgerows on tomato pinworm field infestation at three fields in Homestead, Florida, 1981.

Edge Category	Field 1*	Field 2	Field 3
Hedgerow	6.25a**	4.33ab	4.90a
	5.00a	4.00b	3.85a
	4.65a	--	3.20bc
Road	2.35b	4.58ab	4.10a
	0.60bc	0.20c	3.40ab
Pastures	--	5.82a	--
	--	4.47ab	--
Other crop or tomatoes	1.33b	0.46c	4.15a
	0.95bc	0.33c	1.70bc
	0.35c	--	1.45c

*Mean values of tomato pinworm injuries per plant. Values on respective quadrat adjacent to the edge specified.

**Values with the same letter within a column are not significantly different at the 0.05% level.

Figure 20. Field plan: Fields 1, 2, and 3, respectively, each field was divided into 8-9 quadrats. The shaded areas represent higher insect populations. Homestead, Florida, 1981.


C. equisetifolia
Mango trees
TPW Higher infestation
" Lower infestation
N
S
Grassland
Corn
Sweet potatoes
Tomatoes
Tomatoes
A
B
C

influence of edges on dispersion of TPW adults and that aggregation of TPW is also a function of density. TPW gregariousness was evident in resource exploitation.

Conclusions and General Discussion

In this research useful data were gathered about the pattern of colonization and dispersion of TPW in tomato fields, as well as data about the effects of edges and hedgerows on TPW population dispersion. TPW adult male moths were generally (62%) more abundant on borders than in inner regions of tomato fields (12.4%). TPW foliar injuries were generally significantly higher at the field borders than at 30 and 120 m from the border of the field. The infestation rate progressed toward inner areas depending on initial infestation of the border and sampling date. For instance, fields infested during January had lower infestation than those sampled during March to May.

Three fields showed significantly higher populations on edges surrounded by windfalls, roads, or pastures, and lower populations on edges surrounded by the same crop or other crops.

The accumulation of TPW moths, eggs, and larval injuries on field edges indicate the importance of intensifying sampling in those areas in order to apply control measures to stop infestation progress. There are still many questions unsolved about TPW dispersal patterns. One of them is: Do these moths have a similar dispersal pattern to the one found for *P. gossypiella* by Flick and Noble (1961)? It is possible that TPW generations are divided into colonizers, those that migrate at

higher altitude locating new food sources, and local individuals whose movement inside fields is characterized by a low altitude and erratic flight.

CHAPTER VII
EGG AND LARVAL PARASITISM OF TOMATO PINWORM IN SOUTHERN FLORIDA

Introduction

The tomato pinworm (TPW), *Keiferia lycopersicella* (Walsingham) has been a serious pest of tomatoes in southern California (Oatman 1970), Texas (Wellik et al. 1979) and in Florida (Poe 1974). In southern Florida, TPW is a more serious pest during spring when populations build up as the crop matures. Tomato pinworm larval parasites have been studied by Cardona and Oatman (1971), and seasonal occurrence of parasites has been investigated in southern California by Oatman et al. (1979). Hymenopterous larval parasites attacking TPW in Florida are *Apanteles* spp. (Poe 1974b), *Temelucha* spp., *Sympiesis stigmatipennis* Girault, *Zagrammosoma multilineatum* (Ashmead), and *Parahornius pallidipes* Ashmead (Krombreii et al. 1979). The only egg parasites reported have been *Trichogramma* spp. in southern California (Oatman et al. 1979) and in Colombia attacking the South American pinworm *Scrobipalpula absoluta* (Meyr.) (Garcia et al. 1974).

Reported here are investigations of 1) parasitism of TPW larvae in tomato fields during 1980-81; 2) the parasitism of TPW eggs in the laboratory by the naturally-occurring *T. pretiosum* (Homestead strain) and by a laboratory reared strain of *T. pretiosum* (Texas strain); 3) the effect of host distribution and host density on the parasitization by

Trichogramma spp.; and 4) the seasonal occurrence of the *Trichogramma* spp. in several tomato fields.

Materials and Methods

Larval Parasitization

Twelve to fifteen commercial fields were surveyed for larval parasitism from January 14 through September 5, 1980 and from January 23 through July, 1981. Mined leaves were examined in the fields and taken to the laboratory. Occupied TPW mines were held for adult parasite or moth emergence in an ice cream carton which had about 5 g of white sand in the bottom. No additional food was provided. Therefore, most early TPW instars probably died of starvation. Hosts and parasites were recorded and identified. Percent parasitism was calculated from the numbers of adult moths and parasites which emerged.

Egg Parasitism

Laboratory studies. The parasitism of tomato pinworm eggs by 2 strains of *T. pretiosum* was studied in a laboratory at ca. 25°C, 75 ± 2 RH, and scotophase of 11 h. 'Flora-Dade' tomato plants were exposed to oviposition by TPW adults in an insectary. Eight plants with a total of 405 TPW eggs were exposed to ca. 300 females of *T. pretiosum* (Texas strain) in a cage (24 x 24 x 24 cm) for 24 h. At the same time, excised leaves with a total of 51 eggs were placed in 6 petri dishes (100 x 25 mm) which contained moist filter paper and ca. 3 field-collected females of *T. pretiosum* (Homestead strain) per dish. Eggs were removed after 24 h. exposure and placed (1 egg per dish) in smaller petri dishes (50 x 9 mm).

The eggs were examined initially to determine whether they were parasitized and then observed daily for parasite adult emergence.

Field studies. Three tests were conducted from May to July, 1981 in abandoned tomato fields near Homestead, Florida, to determine effectiveness of naturally occurring *Trichogramma* spp. In the first test, I studied the spatial distribution on the plant of both parasitized and nonparasitized TPW eggs. Only 2 leaves from the upper 1/3 and middle 1/3 portions of the plant were sampled since preliminary sampling indicated few eggs were present on the lower leaves. Fifteen plants were collected randomly from a field which had an avg. of 35.2 eggs/plant. Possible differences in egg density and percentage of parasitism at each level were determined by a student's t-test.

The second test evaluated the effect of host distribution on the level of parasitism, and the relationship between host density and percent parasitism. Two fields were selected as sites for this study: (Field 1) had an avg. of 3.10 eggs per 2 leaves per plant and (Field 2) had an avg. of 0.70 eggs per 2 leaves per plant. The fields were divided into 3 (2 border and 1 middle) sections lengthwise of 0.44 ha each. Two leaves were collected from the middle portions of 80 plants randomly selected per section. Egg parasitism was determined in the laboratory by examining the eggs under a dissecting microscope. Frequency distributions of parasitized and nonparasitized TPW eggs were compared with 3 types of distribution (Poisson, Negative Binomial, and Positive Binomial) and tested by x^2 for goodness of fit. Data were transformed to log (x+1) prior analysis. Differences in egg density among sections of each field were determined by the use of Duncan's

Multiple Range Test. Correlation between egg density and parasitism was analyzed following arc sine transformations.

The third test was conducted to determine the extent of TPW egg paraby *T. pretiosum* in Dade County. Fourteen tomato fields were sampled weekly by collecting 2 middle leaves from 10 randomly selected plants per field. Six of the fields were located in the northern part of the farming area and the rest in the southern portion. Samples were taken to the laboratory to determine degree of parasitism. The survey was suspended as the plantings were destroyed by discing or mowing.

Results and Discussion

Larval Parasitism

Parasitization of tomato pinworm larvae ranged from an avg. of 39.34% in 1980 to 46.26% in 1981. During the study, parasitization averaged ca. 2.5, 22, 51, 40, and 48.27% in January, February, March, April, and May, 1980, respectively. Parasitization averaged ca. 49, 46, 53, and 46% in April, May, June, and July, 1981, respectively. Although parasitism ranging from 40-60% was common during 1980-81, there was not a consistent corresponding increase in parasitism with an increase in host density (Table 36).

Of 3 primary parasites reared from tomato pinworm during 1980, *Apanteles* spp. was the most important, parasitizing 10-66.66% of the larvae. *Temelucha* spp. and *Sympiesis stigmatipennis* were the next most abundant parasitoids. During 1981, (Table 37) 4 parasites were reared. *Apanteles* spp. was again the most important, parasitizing 46% of the larvae, followed by *Parahormius pallidipes*, *Sympiesis stigmatipennis* and *Chelonus phthorimae* in order of importance.

Table 36. Parasitism of the tomato pinworm larvae in tomato fields in southern Florida, Dade County, 1980.

Survey Week	Total Collected	% Total Parasitized	%Parasitized by *Apanteles* spp.	*Sympiesis stigmatipennis*	*Temelucha* spp.
Jan. 14	25	0			
22	25	0			
31	25	10	10		
Feb. 6	46	3.57	0	0	3.57
13	20	33.33	33.33	0	0
19	30	33.00	33.00	0	0
25	25	17.39	17.39	0	0
Mar. 4	35	10.52	10.52	0	0
12	44	62.50	62.50	0	0
19	45	66.66	66.66	0	0
26	25	62.53	58.33	4.20	0
Apr. 2	50	48.26	41.37	6.89	0
7	30	49.07	45.45	1.81	1.81
16	78	38.77	29.52	5.55	3.70

Table 36--continued.

Apr.	3	10	60	60	0	0	0
	9	5	40	40	0	0	0
	22	27	47	47	0	0	0
May	1	15	35	35	0	0	0
	7	25	40	40	0	0	0
	14	31	45	22.43	3.22	19.35	0
	26	155	65.16	63.87	0.64	0	0.64
Jun.	2	28	46.42	42.85	0	3.56	0
	16	109	56.88	55.96	0.91	0	0
	25	65	56.92	55.38	1.53	0	0
July	1	23	56.00	50.00	6.00	0	0
	8	100	73	72.00	1.00	0	0
	17	34	10	9.00	1.00	0	0
Total		627					
	Avg.		42.26	46.03	0.62	0.99	0.027

Table 37. Parasitism of the tomato pinworm larvae in tomato fields in southern Florida, Dade County, 1981.

Survey Week	Total Collected	% Total Parasitized	%Parasitized by *Apanteles* spp.	*S. stigmatipennis*	*Temelucha* spp.
Apr. 23	67	32.38	22.53	2.81	7.04
30	60	34.7	24.39	0.00	7.31
May 7	130	49.31	42.74	0.00	6.87
13	91	51.3	44.73	0.00	6.57
20	130	30.41	29.41	0.00	1.00
Jun. 2	72	62.06	58.62	3.44	0.00
July 4	47	70.00	70.00	0.00	0.00
Aug. 9	40	72.50	72.50	0.00	0.00
Sep. 5	3	66.66	66.66	0.00	0.00
Total	847				
Avg.		39.34	37.50	1.07	1.64

Egg Parasitism

Laboratory studies. The results of the laboratory experiment (Table 38) demonstrated that both strains of *T. pretiosum* can oviposit and develop in TPW eggs. Although the percent parasitism and parasite emergence from eggs parasitized by the Texas strain were 1.2 times greater and 71% less, respectively, than from eggs parasitized by the Homestead strain, these differences may have been due to differences in egg density and searching area rather than differences between strains. It is known that kairomones play an important role in successful parasitism by *Trichogramma* (Seabrok 1977), and this could also account for the observed differences since the Texas strain was reared on Angoumois grain moth (*Sitotroga cerealella*) eggs. The sex ratio was 50:50 (males and females) for the Texas strain and ranged between 50:50-60:40 (males and females) for the Homestead strain.

Field studies. The mean number of TPW eggs and percent parasitism were significantly higher on the middle leaves than upper leaves in test 1 (Table 39). When the egg density per plant was regressed on percentage parasitism from both levels, the r^2 obtained was 0.0181 which indicates lack of correlation. This may indicate a complex of hosts other than *K. lycopersicella* (including *Heliothis zea* [Boddie]). It may also indicate that searching capacity of *T. pretiosum* is a limiting factor in parasitism.

The results obtained from the interaction between host distribution and level of parasitism by *T. pretiosum* is reported in Table 40. The

Table 38. *Keiferia lycopersicella* eggs parasitism by 2 strains of *Trichogramma pretiosum* in the laboratory. T 25±1°C; 75±2% RH.

Parasite Strain	No. Eggs Exposed	% Parasitism $\bar{X} \pm SE$	% Emergence $\bar{X} \pm SE$	Days to Emergence $\bar{X} \pm SE$
Texas	405	68.93±2.91	27.47±1.58	8.33±0.862
Homestead	51	57.96±5.92	93.10±1.36	8.50±2.67

Table 39. Number of *Keiferia lycopersicella* eggs collected from two strata and percent of parasitism by *Trichogramma pretiosum*.

Leaf Location	Total Eggs	Avg. per 21 Leaves	Range	% of Parasitization	
				$\bar{x}$/21 Leaves	Range
Upper	104	6.93 a*	0-19	39.73 a	0-100
Middle	281	18,66 b	0-50	57.80 b	26-100

*Values followed by different letters are significantly different ($P<0.05$) by Students t-test.

Table 40. Distribution of normal and parasitized tomato pinworm eggs in 2 tomato fields.

	No. Plants	$\bar{x}$	s^2	k	x^2
			Field 1		
Total TPW eggs	80	3.09	12.76	1.43	19.39[a]
Parasitized TPW eggs		2.16	5.45	1.65	11.97[b]
			Field 2		
Total TPW eggs	80	0.659	1.35	0.526	3.12[b]
Parasitized TPW eggs		0.42	0.74	0.45	5.46[b]

[a]X^2 value of 19.39 is not below the 5% point of 19.67 (V=9, α=0.05). Therefore, the model is not a good fit to the original counts and agreement with a negative binomial distribution is not accepted at the 95% probability level.

[b]X^2 values of 11.97, 3.12 and 5.46 were well below the 5% point of 19.67 (V=9, α=0.05). Agreement with a negative binomial distribution accepted at the 95% probability level.

distribution of total TPW eggs only fit the negative binomial for the second field. Parasitized eggs in both firled were fit to the negative binomial distribution. Thus, there is an aggregative distribution of TPW eggs and a concomitant distribution of T. pretiosum only when low egg densities per plant are found. These results agree with Morrison and Strong (1980). There were significant differences in host density among the 3 areas of Field 2 but not in Field 1, despite a higher number of host eggs ($\bar{x}$=4.04) (Table 41). The major difference between the fields was that Field 1 was apparently more completely colonized by TPW than Field 2. Egg parasitism ranged from 0-55% for the first field and 0-70% for the second field, despite the lack of correlation (Fig. 21 A and B) (r^2=0.026 and r^2=0.018, respectively) between the percentage of parasitism and the mean egg density for both fields. There was a negative trend in parasitism for egg density higher than 3 eggs/2 leaves (Field 1), and a positive trend when TPW egg density was less than 3 (Field 2). Spatial variations in host density (Morrison and Strong 1980) may result in spatial variations in parasite activity. These results indicate that the distribution of T. pretiosum followed the same distribution as the TPW eggs; however, there was not a consistent increase in percent parasitism with increased host density. Since TPW eggs are not the only hosts for T. pretiosum, the response of the parasite might be the result of spatial differences in the densities of alternate hosts. The limitation of searching capacity, if a reality, or the response to kairomones, if any, may also play important roles in the degree of successful parasitism.

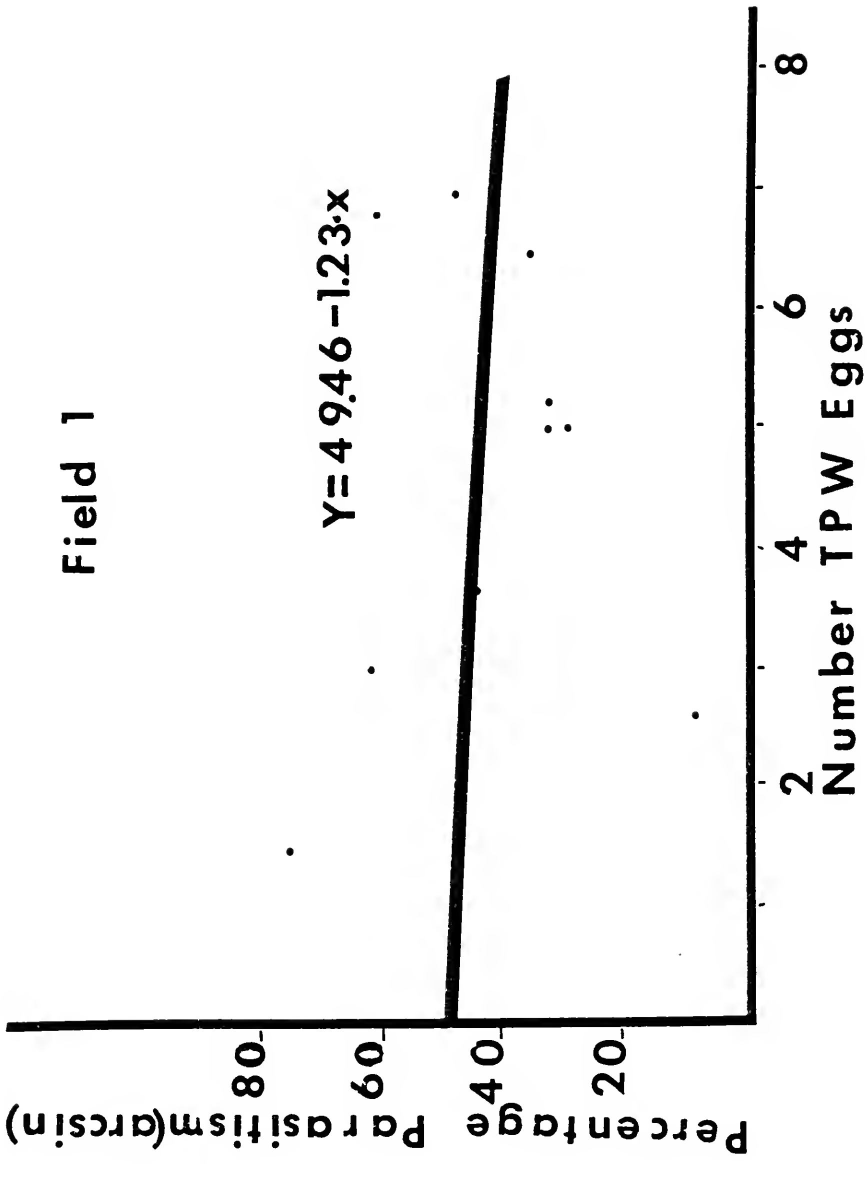
The field survey indicated higher parasitism in the fields located in the northern part of Dade County (Fig. 22A) compared to the fields

Table 41. Parasitism of tomato pinworm eggs by *Trichogramma pretiosum* in 2 fields with different host densities.

Area	No. eggs in sample	$\bar{x}$ of eggs/2 leaves	% Parasitism
		Field 1[a]	
Border 1	363	3.5 a	55
Middle	424	5.0 a	39
Border 2	367	3.5 a	30
		Field 2	
Border 1	51	0.6 a	58
Middle	22	0.3 a	57
Border 2	91	1.00 b	70

[a] Values followed by different letters are significantly different at $P \leqslant 0.05$, Duncan's Multiple Range Test.

Figure 21 A-B. Relationship of _Keiferia lycopersicella_ egg density to percent parasitism by _Trichogramma pretiosum_ in 2 fields.


Field 1
Y=49.46−1.23·x
Percentage Parasitism(arcsin)
80
60
40
20
2
4
6
8
Number TPW Eggs

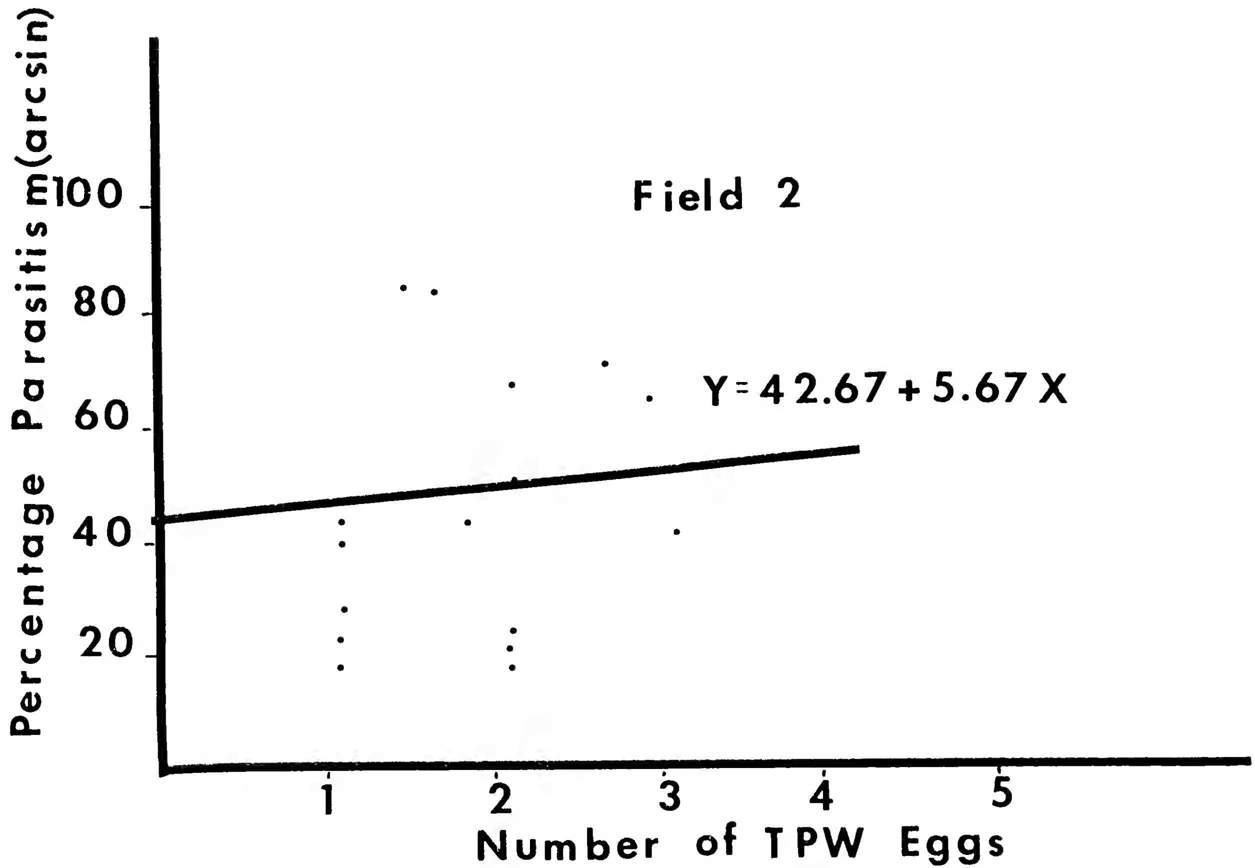
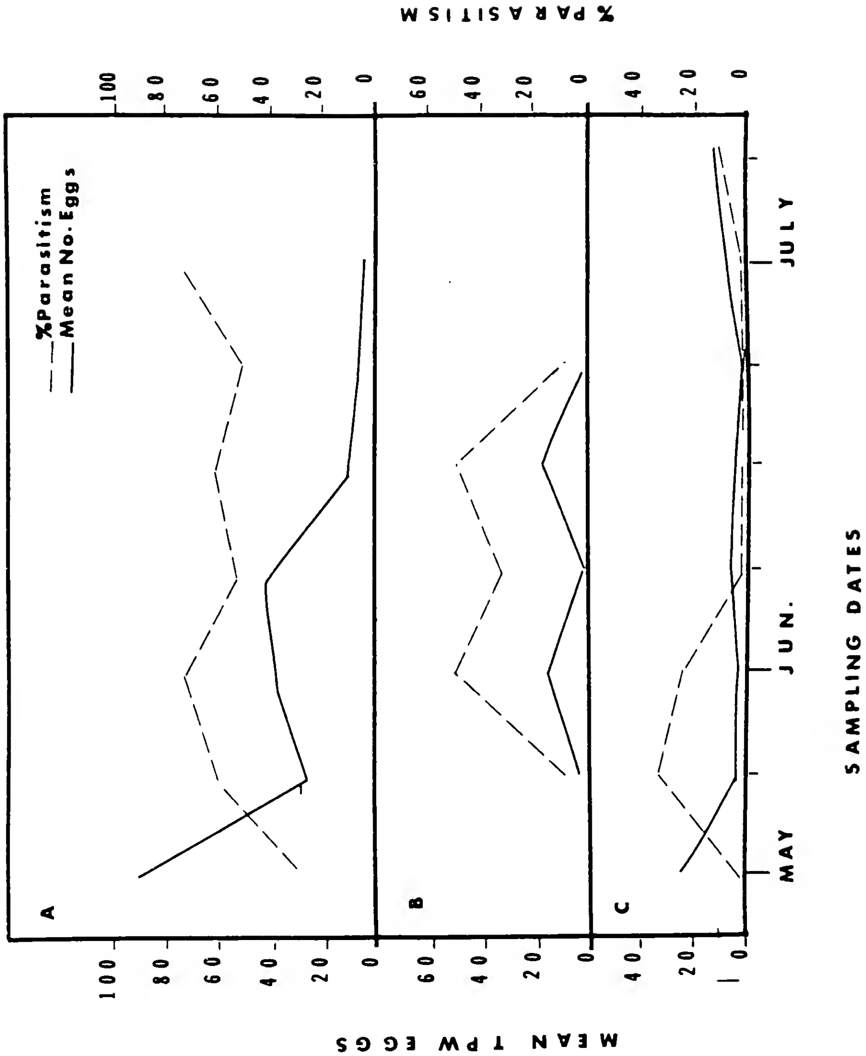

Field 2
Y = 42.67 + 5.67 X
Percentage Parasitism (arcsin)
100
80
60
40
20
1
2
3
4
5
Number of TPW Eggs

Figure 22 A-C. Seasonal occurrence of *Keiferia lycopersicella* eggs and parasitization by *T. pretiosum* in tomato fields located at the (a) northern, (b) middle, and (c) southern areas of Dade County, Florida.



%Parasitism
Mean No. Eggs
A
B
C
MAY
JUN.
JULY
SAMPLING DATES
MEAN TPW EGGS
% PARASITISM

located in the southern part (Fig. 22C). Parasitism of TPW eggs ranged from 30% in May to 65% in July for the northern fields. In the southern fields parasitism ranged from 0% in May to 15% in July. The average parasitism for both areas for the study period was 26.9%. Although parasitism ranging from 33-73% was not uncommon when density was higher than 5.2 eggs/2 leaves, there was not a consistent corresponding increase in parasitism with an increase in host density except for 1 field surveyed (Fig. 22B). It is known that the frequency with which a parasite finds hosts is a product of several components. Among them, Burnet (1958) and Hassell (1966) found that the nature of host distribution has considerable influence on the response of entomophagous insects. Studies of the incidence of *T. pretiosum* on other hosts (*Heliothis* spp.) should be conducted in tomato fields. This information is needed to understand better how *T. pretiosum* can be manipulated for maximum benefit of the tomato producer.

General Discussion and Conclusions

Data obtained from research on parasitism of TPW eggs and larvae in southern Florida indicate that *Trichogramma pretiosum*, as an egg parasite, and *Apanteles* spp., as a larval parasite, are the most abundant natural enemies. The parasitoid population increased during May-June, when most southern Florida tomato fields are at post-harvest. This may also indicate insecticide resistance of the parasite species from continuous insecticide applications. Further research is suggested on releases of these parasites on post-harvested fields to reduce TPW resurgence during the following season.

CHAPTER VIII
EFFECTS OF RAINFALL AND RELATIVE HUMIDITY ON IMMATURE STAGES OF THE TOMATO PINWORM UNDER GREENHOUSE AND FIELD CONDITIONS

Introduction

Some information concerning the effect of temperature and various environmental factors on *Keiferia lycopersicella* (Walsingham), the tomato pinworm (TPW), is available in the literature (Weinberg and Lange 1980, Poe 1974b, McLaughlin et al. 1979). Little has been published, however, concerning the study of rainfall and humidity influencing the rate of population increase of this insect. Effects of rainfall and humidity on pests of the same family have been studied by Simmons and Ellington (1933), Hofmaster (1949), Warren (1956), and Clayton and Henneberry (1982). In general, they found that rainfall and humidity may reduce or increase abundance of different stages of the Gelechidae species studied. This paper describes a study of the relationship between rainfall and survival of the egg, larval, and pupal stages of TPW the laboratory and in the field.

Materials and Methods

Seasonal Occurrence of TPW in Experimental Plots

To find a possible relationship between temperature and rainfall and egg deposition by the TPW, oviposition was studied on 8 non-staked tomato plantings cv. Flora-Dade (Nov. 3, 1979; Dec. 5, 1979; Jan. 8, 1980; Oct. 30, 1980; Nov. 25, 1980; Dec. 30, 1980; Jan. 30, 1981;

Feb. 28, 1981). Tomatoes were seed-planted at the Agricultural Research and Education Center, University of Florida, Homestead, Florida. Each planting (ca. 450-947 plants) was set in raised beds (3-5) (ca. 45 m long) of Rockdale soil and mulched with light colored plastic. Plants were spaced 38 cm apart. Oviposition per plant was averaged weekly for 3 plantings during 1980 and for 5 in 1981. Each weekly sample consisted of 10-20 plants selected at random. Temperature and rainfall regimes during February through May, 1980 and January through May, 1981 were determined by the Climatological Weather Station at the Agricultural Research and Education Center, Homestead, Florida.

Seasonal Occurrence of TPW in Southern Florida

Studies were conducted in 12-15 commercial fresh market tomato plantings in Homestead, Dade County, Florida during 1980-81. The fields were part of a survey program. Every crop differed in size and practices such as insecticide application, but horticultural practices were similar. Each planting during 1980 was systematically sampled for larval injuries by inspecting the whole plant. During 1981, I limited the sampling to inspection of 2 of the middle leaves on each plant. A total of 20 plants per field was sampled. Each planting was sampled before and after harvest, and sampling was suspended when the grower disced or mowed the crop. Surveys continued when new plants emerged in those fields. The survey during 1980 was concluded during October, when the fall tomato crop was planted. The survey during 1981 was concluded in July, 1981. During 1981, pheromone sticky traps (Pherocon 1c®) baited with pheromone (95.3%-(E)-3-Tridecen-1-01 Acetate; 4.5%-(Z)-4-Tridecen-1-01 Acetate) were placed in 6 fields. Male adults trapped

were recorded weekly, and the mean number compared with immature stage infestation levels in the field. Again, a possible relationship between population increase and environmental factors is expressed.

Effect of Plant Water on Oviposition

Ovipositional preference related to water content was studied by collection of 2 tomato plants of 5 different ages. Plants were naturally infested with TPW eggs in the experimental field mentioned above. The plantings were 6, 5, 4, 3, and 2 months of age. Every week, plants were pulled and taken to the laboratory where the numbers of eggs were recorded. After this, the fresh weight of plant leaves was measured (g), and 2 days later, the dry weight measured. Water content per plant was estimated as the difference between fresh weight and dry weight. The experiment lasted 6 weeks until plants approached 7.5, 6.5, 5.5, 4.5, and 3.5 months old. Plant water content and oviposition with respect to planting time were analyzed and compared by Duncan's Multiple Range Test at the 0.05 level.

Effect of Simulated Rainfall on Larvae

An average of 5 second instar larvae per plant, reared on 30 day-old potted tomato plants, was used to determine the effect of rainfall on larval mining. Each plant had 8 $\pm$ 1 leaves. The first treatment consisted of a simulated continuous drizzling (mist) for 24 h. Total water sprayed per plant was 100 cc per day. Drizzling was simulated by use of an automatic mister that sprayed fine droplets for 1 minute every 5 minutes over the foliage. The second treatment consisted of spraying

the foliage with 50 ml of water 2 times a day. Rainfall was simulated by use of a manual sprinkler. The third treatment was soil irrigation with 100 cc of water per day. The number of injuries per leaf was counted 2 days after the experiment was set, and counts countinued every other day for during 9 days. Treatments were replicated 3 times. The mean numbers of injuries per plant were obtained and compared by analysis of variance (ANOVA). Fresh weight of leaves consumed was recorded (5 days after the experiment started) from randomly selected infested leaves, following the procedure explained in Chapter I, in order to determine leaf consumption under different water regimes. The larval head capsule width was measured to determine larval instar.

Effect of Simulated Rainfall on Pupae

Newly formed pupae of TPW were subjected to the following conditions: a layer of coarse white sand was placed in a series of boxes (21 x 30 x 23 cm), constructed of dry lumber, each fitted with a solid lid and a screen (1 mm diam) in the bottom to help water drainage. Boxes were surrounded with Tanglefoot® to avoid predation by ants. The boxes were held in the greenhouse at 24 $\pm$ 3°C. The pupae used in this study were taken from a culture of 1st generation insects. Insects were reared in a 12:12 light-dark cycle at a 24 $\pm$ 3°C and 75 $\pm$ 2% RH. A total of 20 pupae was placed in each box. Two hundred ml (97 $\pm$ 2% RH), 100 ml (80 $\pm$ 1% RH), 50 ml (60 $\pm$ 10% RH), and 0 ml (27 $\pm$ 3% RH) of water were applied every other day with a manual sprinkler. Treatments were replicated 3 times. Percentages of emergence were taken of the number of adults emerging per box. Data were transformed by arc sine procedures before the analysis. Data are presented as actual percent emergence.

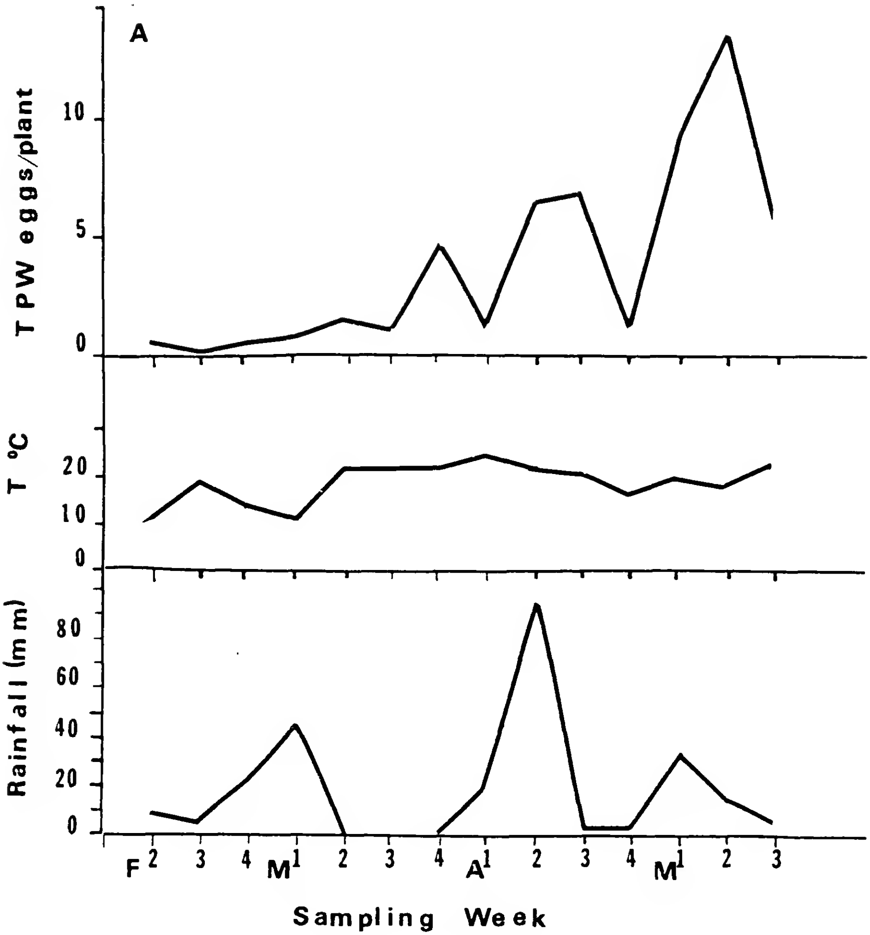
Results and Discussion

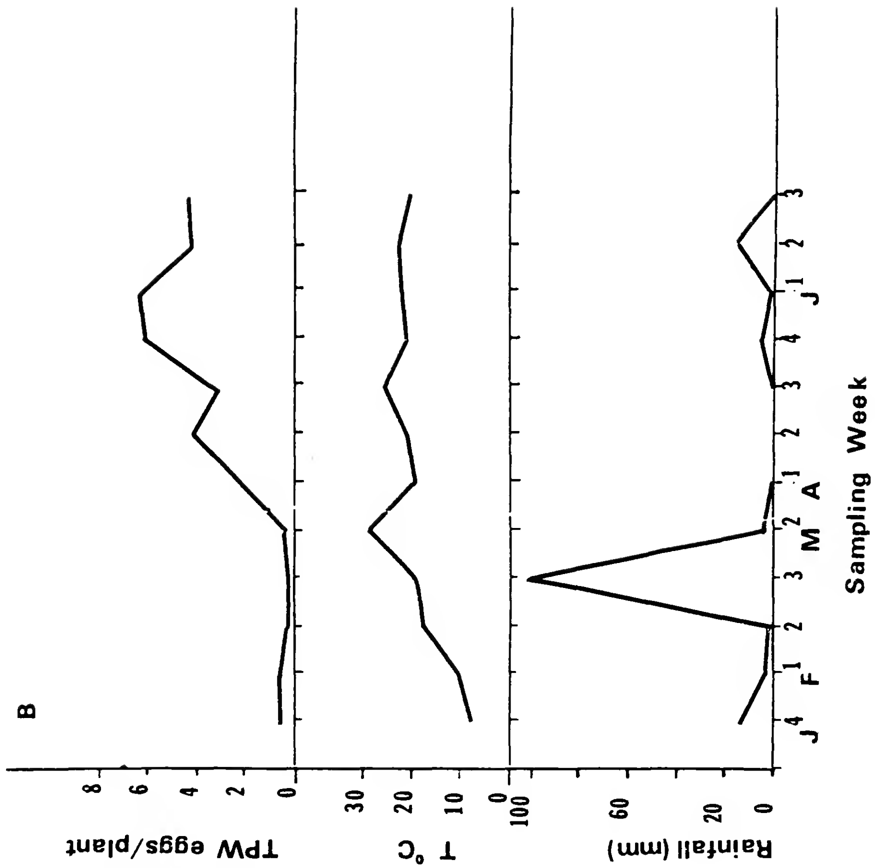
Seasonal Occurrence of TPW Eggs in Experimental Plots

TPW oviposition peaked early during 1980 (Fig. 23). Numbers during this year were higher than during 1981. The number of eggs increased sharply during the first 3 months of 1980, and this increase was maintained until mid-May, 1980, when the tomato leaf area decreased sharply. Average daily temperature in the field increased after the middle of March, 1980, but remained stable around 20-25° C during March through April, 1980. The amount of rainfall was negatively correlated with oviposition. Oviposition increased when rainfall was zero during March and decreased at the beginning of April when rainfall increased. The increase in rainfall seemed to be related to low ovipositional activity during April, and its delayed effects can be seen in Fig. 23.

During 1981, increased oviposition was observed as temperature increased and rainfall decreased. The temperature increased during January through April, stablizing around 21-24° C during the later months. When rainfall was low the pattern of oviposition increased abruptly. This may suggest a pattern in which moth activity can be related to oviposition patterns. This result agrees with the results found by Simmons and Ellington (1933) who stated that high humidity reduced 13 times the average number of eggs laid by *Sitotroga cerealella* (Gelechiidae).

Figure 23. Seasonal abundance of TPW eggs in experimental fields, related to temperature and rainfall regimes during A) 1980 and B) 1981, in Homestead, Florida.


A
TPW eggs/plant
10
5
0
T °C
20
10
0
Rainfall (mm)
80
60
40
20
0
F 2 3 4 M 1 2 3 4 A 1 2 3 4 M 1 2 3
Sampling Week


B
TPW eggs/plant
T °C
Rainfall (mm)
Sampling Week
J F M A J

Seasonal Occurrence of TPW Larvae in Southern Florida

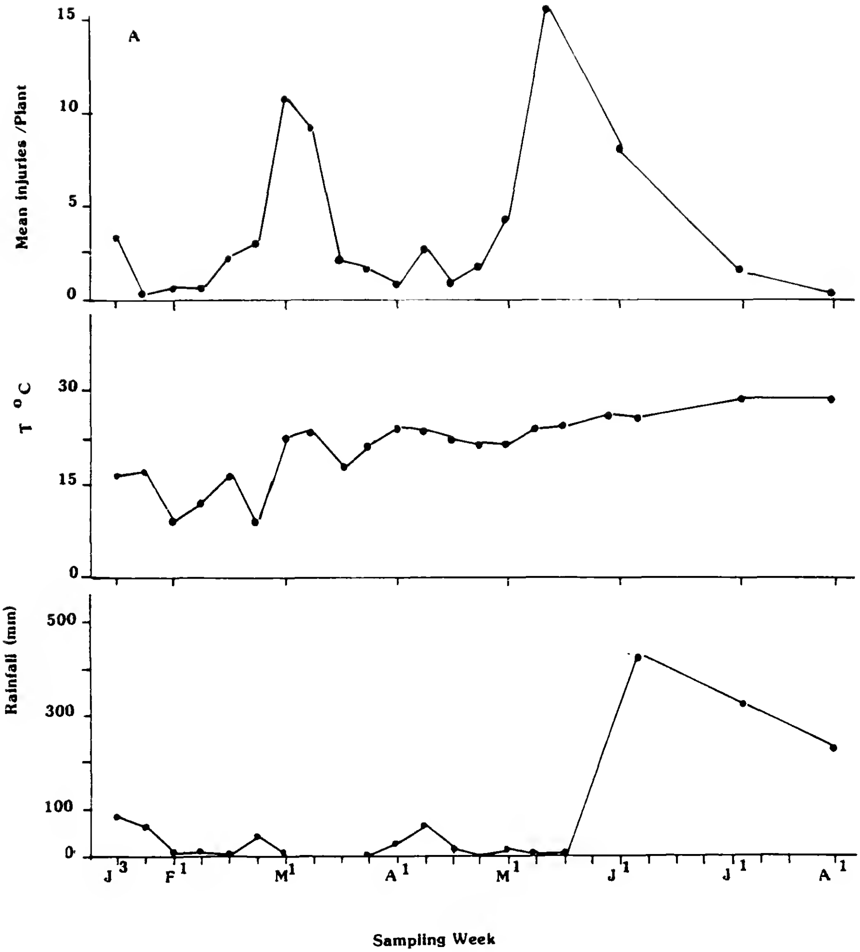
TPW larval density decreased from January 3 through the 2nd week of February, then peaked at the beginning of March, 1980 (Fig. 24). The population declined through March and the 1st weeks of April, but steadily increased during the 3rd week of this month, to reach the highest density in May. Most growers disced and mowed the tomato fields during the 4th week of May, causing populations to decrease through June-October. Despite this, larval injuries (Fig. 24) were found on volunteer plants during these months. I consider that field infestation is dependent on temperature and rainfall regimes and crop management. It is observed in Fig. 30 that despite an increase in temperature during June-August, rainfall also increased during these months, indicating a possible negative effect on pest abundance.

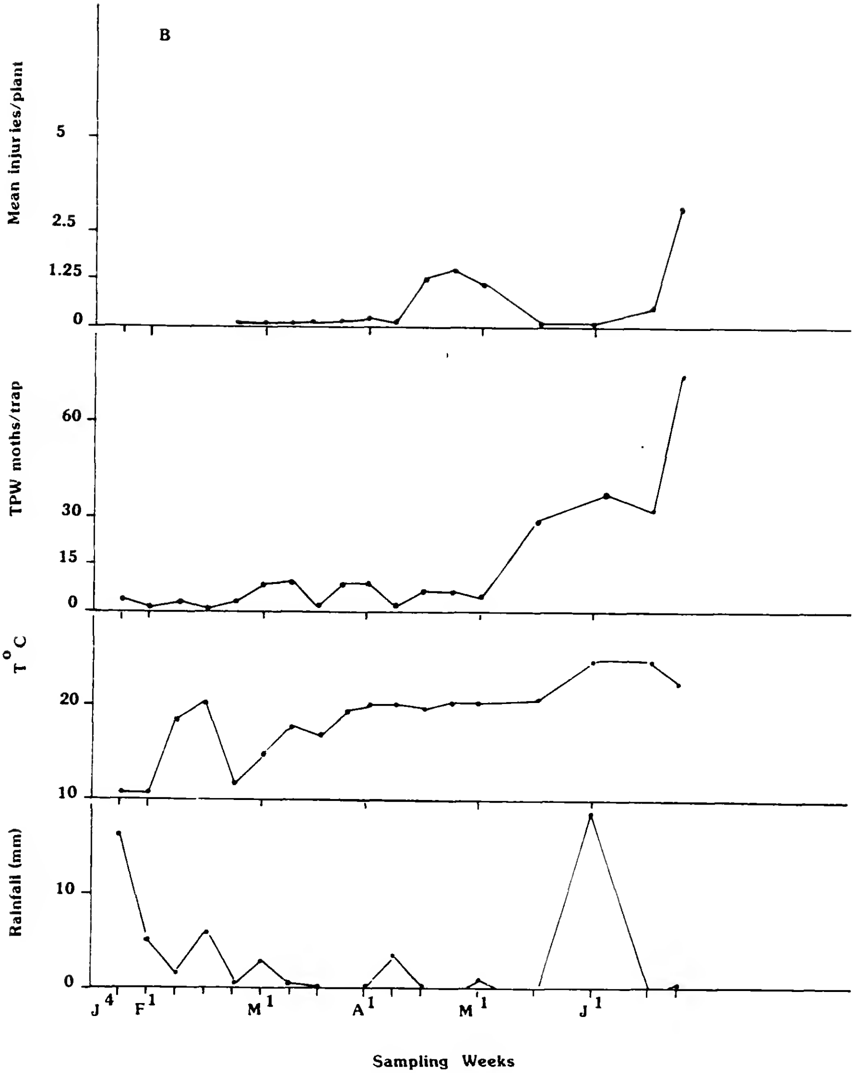
During 1981, TPW larval density in commercial tomato fields was almost negligible. Population densities were low as late as February 25, and population growth was not evident until early April. Early, low temperatures seemed to be the factor suppressing the pest this year; however, the high temperatures and low rainfall coincided with the pest peaks.

Effect of Plant Water on Oviposition

Effect of oviposition response to leaf water content of the whole plant has been demonstrated for *Pieris rapae* (L.) by Wolfson (1980). Highest water content of each plant was found in those plants planted

Figure 24. Seasonal abundance of TPW larvae in tomato fields, related to temperature and rainfall regimes during 1980-81, in Homestead, Florida.


A
15
10
5
0
Mean injuries /Plant
T °C
30
15
0
Rainfall (mm)
500
300
100
0
J 3
F 1
M 1
A 1
M 1
J 1
J 1
A 1
Sampling Week


B
Mean injuries/plant
5
2.5
1.25
0
TPW moths/trap
60
30
15
0
T °C
20
10
Rainfall (mm)
10
0
J 4
F 1
M 1
A 1
M 1
J 1
Sampling Weeks

latest (4 weeks old). Greater mean numbers of eggs obtained (Table 42) corresponded again to the youngest crop followed by those crops 3, 4, 5, and 6 months old. The numbers of eggs oviposited among the oldest crops were not significantly different. When plantings were 3, 4, 5, and 6 months old, the water content of plants was 1.46, 2.69, 9.79, and 8.72 times less, respectively, than that found on 2-month old plants. These results may indicate the possible relationship between water content and oviposition; however, when these parameters were regressed, the coefficient of determination was as low as 0.27, despite an F value of 7.06. Perhaps the high (71.37%) CV obtained tended to minimize the effect of this relationship. Oviposition preference is not only related to water content, but possibly to the amounts of other substances in the plant leaf.

Effect of Simulated Rainfall on Larvae

The data in Table 43 show the effects of rainfall on the number of injuries on each plant. The numbers of larval injuries per plant were always significantly lower when water was sprayed on the foliage. Thus, compared to the soil irrigated treatment, the numbers of injuries were reduced 53% and 48% when water was applied to the foliage. The differences during 10 days after treatment are shown in Fig. 25. It was found that when water was applied continuously to the foliage, the larvae stopped mining the leaves and started feeding externally on the leaf, or constructed a silk tent to protect against the excessive amount of water. Leaf consumption was also reduced 1.46 and 3.57 times when the double and continuous water spray was used. Since there was no

Table 42. Plant water content in five tomato plantings related to oviposition by the tomato pinworm.

Planting No.	Leaf Water Content (Fresh Weight - Dry Weight) (g)	Mean Eggs/Plant
1	11.05 d*	0.56 d
2	9.05 e	0.46 e
3	35.83 c	0.63 c
4	65.99 b	1.51 b
5	96.43 a	1.84 a

* Numbers followed by different letters were significantly different by Duncan Multiple Range Test (P=0.05).

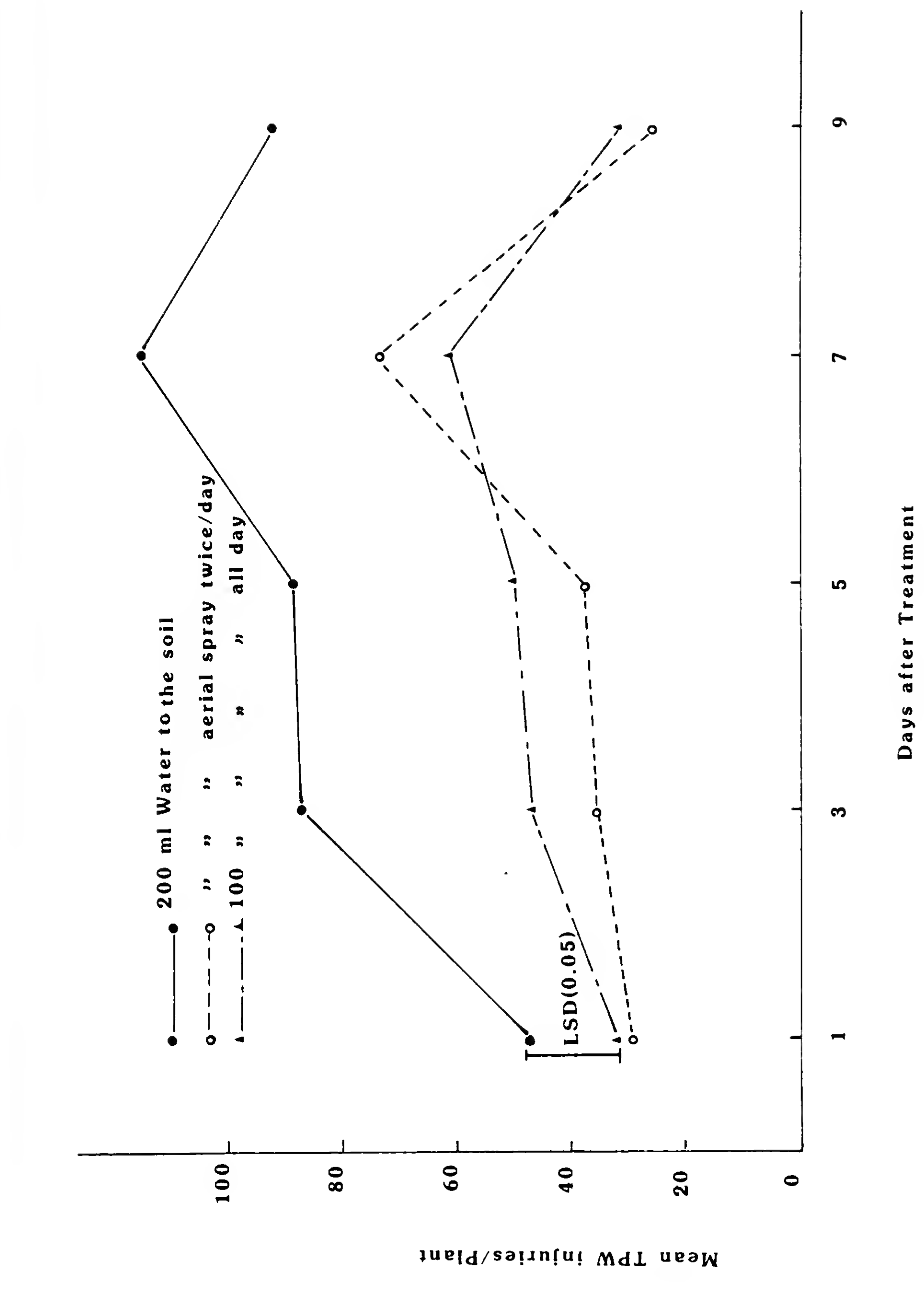
Table 43. Effect of simulated rainfall on foliar larval injuries caused by the tomato pinworm Keiferia lycopersicella on plants grown under greenhouse conditions.

Treatment	Average Number of injuries/plant	Leaf Consumption (mg)*
100 cc water applied daily as a mist	45.78 b**	353.2 b
200 cc water applied as spray twice a day	42.071 b	853.2 ab
200 cc water applied to the soil every other day	86.667 a	1261.0 a

* Leaf consumption measured days after treatment on larvae.

**Values followed by different letters were significantly different by Duncan Multiple Range Test (P=0.05).

Figure 25. Mean number of TPW injuries per plant during 9 days of simulated rainfall under greenhouse conditions, avg. daily temperature $25 \pm 2°$ C.


200 ml Water to the soil
„ „ „ aerial spray twice/day
100 „ „ „ „ „ all day
LSD(0.05)
Mean TPW injuries/Plant
0
20
40
60
80
100
1
3
5
7
9
Days after Treatment

water stress in the treated plants, we may consider the physical action of the simulated rainfall as a negative factor that may cause a larval reaction to stop or delay feeding.

Effect of Simulated Rainfall on Pupae

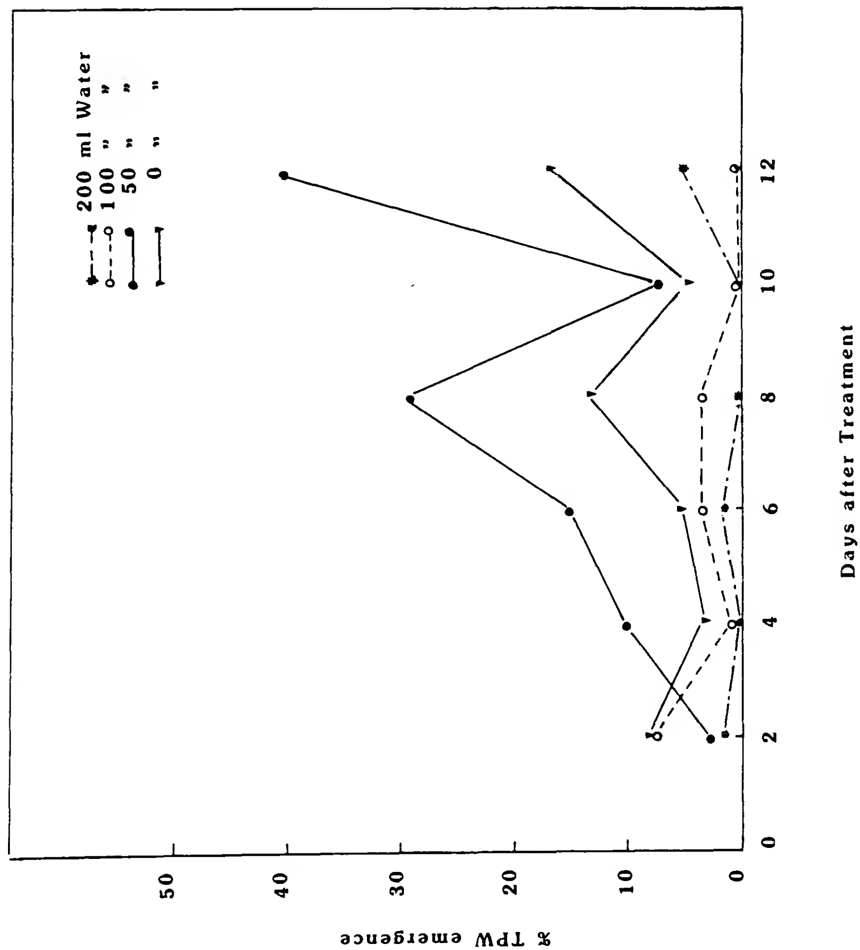
An intermediate level of water in the soil increased TPW emergence (Table 44) (Fig. 26). Analysis of the data also indicated that when moisture levels increased (100-200 ml water), or decreased (0 ml water), emergence was 93%, 66%, and 48% less, respectively, than when 50 ml of water were applied. Emergence from the control (no water) was 6.92 and 3.54 times greater than when 200 and 100 ml were applied. These results are similar to those found for *P. gossypiella* by Clayton and Henneberry (1982). Other factors, such as soil type or depth of burial, may be expected to have an effect on emergence. The ability of TPW larvae to locate places to pupate may indicate a characteristic common among some members of the Gelechiidae. It was observed that the South American pinworm (*Scrobipalpula absoluta*) does not pupate in heavy clay-wet soil, but prefers dry leaves in the canopy as a substrate (Garcia et al. 1974). The combined effect of temperature and high relative humidity upon mortality factors of the TPW in southern Florida should be investigated. It has been demonstrated by Simmons and Ellington (1933) that egg laying of the angoumois moth is reduced when humidity increases, but adult longevity is extended. Furthermore, it was determined by Hofmaster (1949) that outbreaks of the potato tuberworm occurred regularly after unusually hot and dry seasons, and such conditions are considered as the most favorable for potato tuberworm development.

Table 44. Mean percentage of tomato pinworm adults emerged by day after pupal treatment with different simulated rainfall regimes.

Treatment ml Water	Mean Percent of Emerged Adults/Day
200	1.250 b*
100	2.94 b
50	17.76 a
0	8.67 b

* Mean values followed by different letters were significantly different by Duncan Multiple Range Test (P=0.05).

Figure 26. Percentage of TPW adult emergence under greenhouse conditions after treatment of pupae with 3 regimes of artificial rainfall (200, 100, 50, and 0 ml water), temperature $24 \pm 3°$ C.


200 ml Water
100 " "
50 " "
0 " "
% TPW emergence
0
10
20
30
40
50
0
2
4
6
8
10
12
Days after Treatment

Conclusions and General Discussion

In conclusion, it is clear that we are just beginning to understand the influence of the environment on TPW populations. Useful data were gathered in this research about effects of rainfall on TPW immature stages.

For instance, during 1980, the highest (7-14) number of eggs per plant coincided with lower rainfall (2.5-11 mm). This result was reinforced by the increase in oviposition (2-7 eggs/plant) during 1981 compared to the low amount (0-8 mm) of rainfall obtained. This indicates that oviposition is reduced when rainfall is higher than 10 mm. Research on female ovipositional behavior related to rainfall patterns needs to be studied more closely. Knowledge of this relationship will permit better egg forecasting.

The study of plant water effect on oviposition demonstrated that a larger amount (96.43 g) of plant water coincided with a greater (1.84) number of eggs per plant. At this point, it is not clear if this result is related to the presence of a soluble plant chemical or physical plant characteristics (e.g. leaf turgidity). Presence of chemicals at different plant stages should be investigated to relate them to TPW oviposition. For instance, higher water content occurred when the plant was at the first reproductive stage (TR_1). Plant water decreased during the second reproductive stage (TR_2) through senescence (S_1). This knowledge will be useful for TPW plant resistance studies as well as better monitoring of TPW eggs on tomato plants.

The lowest amount of rainfall (0 mm) during 1980 coincided with the greatest number of injuries per plant (10-15). During 1981, more (1.25-2.5) TPW injuries occurred per plant where there was little rainfall (0-0.5 mm). Data from the effect of simulated rainfall on TPW injuries reinforced the results obtained in the field. Simulated rainfall reduced by 50% the number of injuries per plant. The possible use of this practice as a TPW reduction factor is not advised because of the tendency to increase plant pathogen virulence. The results, however, partially explain why during a prolonged rainy season, the number of TPW injuries per plant are reduced.

Simulated rainfall affected adult emergence. The highest (17.76) mean number of TPW adults emerged when an intermediate amount of rainfall (50 ml) was applied to TPW pupae. Only 8.67, 1.25, and 2.94 TPW adults emerged per day when 0, 200, and 100 ml of water were applied. Therefore, lower adult emergence is expected during the rainy season in southern Florida.

CHAPTER IX
INFLUENCE OF POST-HARVEST TOMATO FIELDS ON
THE POPULATION DYNAMICS OF TOMATO PINWORM

Introduction

Elmore and Howland (1943) and Poe et al. (1975) mentioned that cultural practices such as burning crop residues and discing the tomato fields helped reduce *Keiferia lycopersicella* (TPW) populations. The effect of post-harvest practices on survival of this insect during noncropping periods is important in a pest management program for TPW in southern Florida, since larger insect populations appear to coincide with the post-harvest field season. Reported here are investigations on the effect of cultural practices on oversummering populations of TPW in southern Florida.

Materials and Methods

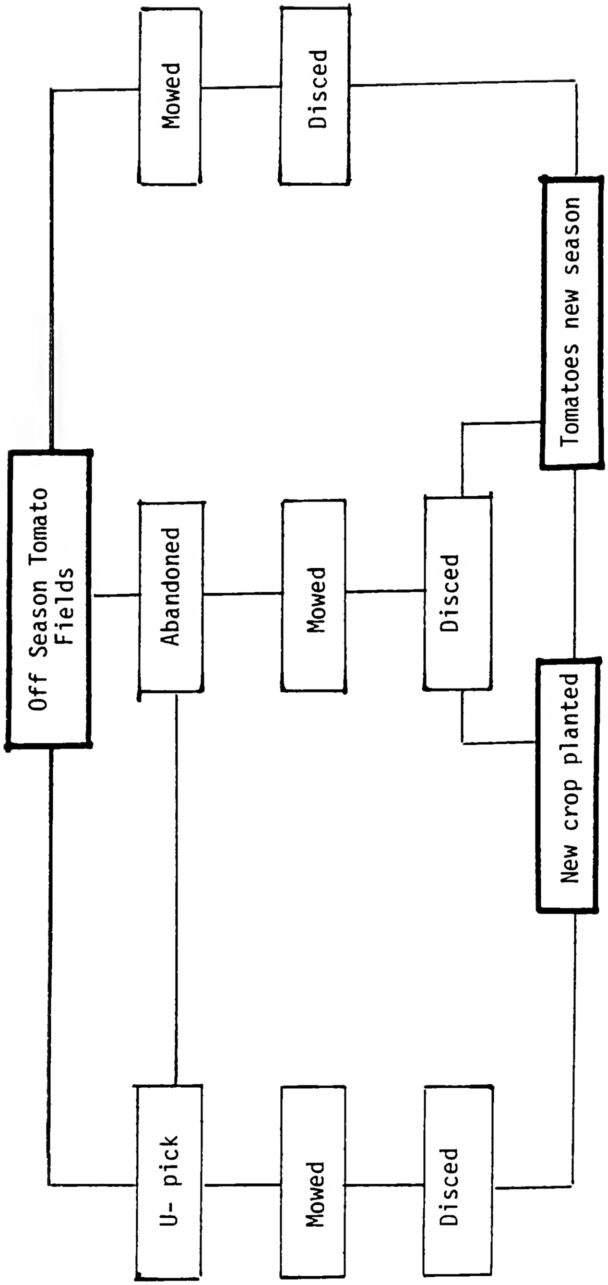
Post-harvest survival of TPW related to cultural practices in the field was investigated in two separate experiments in Homestead, Dade County, Florida. The first experiment was conducted during 1980 in 17 fall-winter planted commercial fields. The investigation is summarized here only for 2 typical fields.

A tomato field in southern Florida can be classified after the main harvest as: 1) "U-pick" field, 2) abandoned field, and 3) disced and mowed. The "U-pick" fields are those plantings which are often rented to a low income person who allows the public to harvest tomatoes for a

reasonable fee. Generally, the field is not sprayed with insecticides after commercial harvest. The second category corresponds to those fields which are left without any supervision for at least 1-2 months. the third category is fields which are mowed, burned and finally disced after the main harvest. Each category can become a subcategory (Fig. 27). The number of tomato plants and number of TPW injuries were monitored in those fields by randomly selecting 10 m^2 in each field. The presence of plants and TPW injuries per m^2 measured and averaged for the 10 m^2 per field. This survey was carried out over 4 months, depending on the cultural activities practiced.

The objective of the second experiment (1981) was to determine which cultural practices increased the TPW population. The experiment was done at the Agricultural Research and Education Center, in Homestead, Florida. Experimental fields were planted during October 30, November 25, and December 30, 1980. Each planting was set in raised beds and mulched with light colored plastic. Plants were spaced 38 cm apart. Each planting was 324 m^2 and split into 3 treatments (108 m^2 each). Three weeks after treatments were set, the numbers of tomato plants and TPW injuries on 5 m^2 randomly selected were monitored on each subplot. The survey was conducted biweekly for 1.5 months. Means were analyzed by a nested analysis of variance (Sokal and Rohlf 1969). Mean number of plants and number of injuries per m^2 were separated by use of Duncan Multiple Range Test.

Figure. 27. Tomato field status following the main harvest under S. Florida conditions. Homestead, Florida, 1980.


Off Season Tomato Fields
Abandoned
Mowed
Disced
U- pick
Mowed
Disced
Mowed
Disced
Tomatoes new season
New crop planted

Results and Discussion

Survey--1980

The survey demonstrated that 7 (41%) of the fields inspected during 1980 were disced and mowed (Category 1) immediately after harvest. Of the 10 remaining fields, 7 became "U-pick" fields (Category 2) and 2 (17.64%) were considered abandoned (Category 3). Two fields from Category 1 were planted again with a summer crop (bean or squash), the rest of the fields (5) from this category had tomato plant emergence and regrowth of plants during a 2-month period. In Category 2, 4 of the 7 "U-pick" fields were disced and mowed in a 2-month period; the remaining ones (2) were abandoned. During the new fall tomato growing season, 47% of the 17 inspected fields in the previous season were planted to tomato again.

In Fig. 28 are shown the mean number of plants and foliar injury per m^2 in 2 fields. Field 1 had an increase in the number of injuries per plant until the field was disced. When the field was planted with beans (*Phaseolus vulgaris*), the number of tomato plants germinating and the number of TPW injuries per m^2 increased up to 13 and 14, respectively. The second field ("U-pick") showed a slight increase in number of plants per m^2 until discing. After this practice, the number of TPW injuries increased to 8 times greater than before discing. It was observed that when beans and squash followed tomato planting, volunteer tomato plants were more numerous than when the field was disced and abandoned. This effect is possibly related to the irrigation and type

Figure 28. Number of tomato plants and TPW injuries per m^2 in 2 post-harvested tomato fields. Homestead, Florida, 1980.

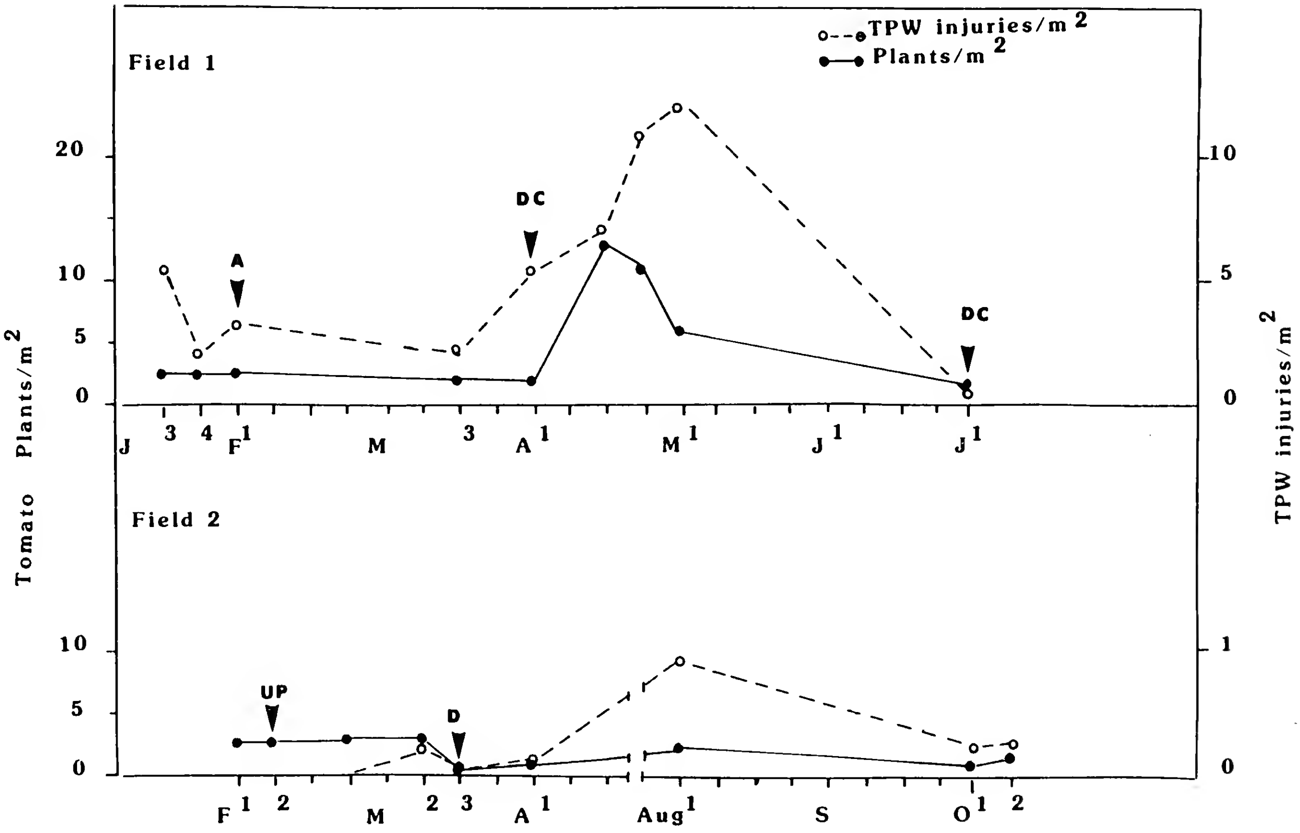

Field 1
o--o TPW injuries/m 2
●—● Plants/m 2
A
DC
DC
Field 2
UP
D
Tomato Plants/m 2
TPW injuries/m 2
20
10
5
0
10
5
0
10
5
0
1
0
J 3 4 F 1 M 3 A 1 M 1 J 1 J 1
F 1 2 M 2 3 A 1 Aug 1 S O 1 2

Table 45. Effect of crop age of post-harvested tomato plants on volunteer plants and number of tomato pinworm larval injuries.

Crop Planted	Months After Harvest	Mean Plants/ m^2	Mean TPW Injuries/ m^2
Oct. 30, 1980	3	0.1222 b*	0.1389 b
Nov. 25, 1980	2	0.41 b	0.641 b
Dec. 30, 1980	1	2.53 a	4.006 a

* Values followed by different letters were significantly different according Duncan Multiple Range Test (P=0.05).

of herbicide used in the new crop. Field 2 had a slower increase of plant and larval levels after entering a period of abandonment.

Experiment--1981

Results of the second experiment are expressed in Table 45. Tomato crops planted earlier (Oct.-Nov., 1980) has a significantly lower mean number of volunteer plants than the younger one (Dec., 1980). The mean number of TPW injuries was significantly larger in the younger planting than in the others. Abandoned fields had generally lower numbers of plants than mowed and disced fields. The numbers of injuries were similar for any treatment. Effects of planting time on the treatments were obvious (Tables 46-47). The older planting had a greater number of injuries per plant when abandoned than when the planting was mowed or disced. The second planting (Nov., 1980) again had more injuries per m^2 if abandoned compared to the other treatments. In contrast, the younger planting had a higher number of injuries when disced and mowed than when abandoned. The effects are explicable. Older fields have fewer viable seeds that will germinate than those from younger fields in which seeds are immediately incorporated into the soil.

Effects from secondary host plants as oversummering sites have been suggested for the TPW. The availability of off-season tomatoes helps to maintain the TPW population but also helps in build up of natural enemies. Use of abandoned or "U-pick" fields for pest management of TPW by constant release of parasitoids would be a practice to reduce pinworm populations for the next season, without interfering with the farmer interests and environmental concerns.

Table 46. General effect of cultural practices on volunteer tomatoes and infestation by tomato pinworm.

Treatment	Mean Plants/m^2		Mean TPW Injuries/m^2
Disced	1.377	a*	1.46
Mowed	1.15	a	1.70
Abandoned	0.54	b	1.67

* Values followed by the same letter are not significantly different according to Duncan's Multiple Range Test.

Table 47. Effect of planting age and cultural practices on volunteer tomato plants and number of TPW injuries.

Planting	Treatment	Number plants/m^2	Number injuries/m^2
1) Oct. 30, 1980	disced	0.00	0.00
	mowed	0.075 b*	0.13
	abandoned	0.316 a	0.28
2) Nov. 25, 1980	disced	0.017 c	0.16 b
	mowed	0.283 b	0.16 b
	abandoned	1.066 a	1.51
3) Dec. 30, 1980	disced	2.333 b	4.233
	mowed	2.166 a	4.55
	abandoned	1.333 a	3.23

* Values followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P=0.05).

Consequently, effects of cultural practices to help control the TPW in tomatoes can be considered in two ways. First, these practices may be considered in relation to the pest density or, second, in relation to the impact on natural control agents. For the most part, cultural measures usually modify the environment to the disadvantage of the pest (Anonymous 1979). However, cultural practices can destroy the host and the parasites or natural enemies of the host. In southern Florida, the widespread cultural practices could account for part of the insect reduction during the past 10 years. The impact of some of the post-harvest practices related to pest density has been demonstrated in this study.

GENERAL DISCUSSION AND CONCLUSIONS

In this research useful data were gathered about tomato plant phenology, spatial distribution of eggs and larval populations of *Keiferia lycopersicella* (Walsingham), and effects of tomato pinworm (TPW) larvae on tomato yield. Studies of the effects of natural enemies, rainfall, edgerows and cultural practices on the population dynamics of this insect provided important data for better management of TPW.

A different IPM approach is suggested based on data about different stages of development of tomatoes. 'Flora-Dade' tomato phenology was described based on 3 major stages: vegetative, reproductive and senescent. Vegetative stages (TV_1-TV_2) were determined by presence of primary leaves and secondary vegetative growth on plants 1-35 days old. Reproductive stages TR_1-TR_2 were based on numbers of flowers and fruits on plants 40-110 days old. The results indicate that reproductive stages (TR_1-TR_2) should be subdivided so more precise pest management decisions can be made. This classification can be refined by dividing the TR_2 stage into 2 substages. One stage is during fruit formation and the other stage is during harvest maturity. The rationale behind this is to improve economic thresholds during fruit formation and just before harvest.

Research on sampling TPW eggs indicated that high cost (\$8.4-84) of egg sampling combined with high $SE/\bar{x}$ ratio (20-100) reduce the practicality

of sampling this immature stage in the field. Data on TPW distribution indicated that eggs were found mainly (44-68%) in the middle-upper canopy of the plant. Therefore, proportional sampling can be allocated for the upper external stratum (nh=6) followed by the middle internal stratum (nh=5), and 3, 4, 4 and 1 samples for lower external, upper, middle and lower internal canopies, respectively. Apparently, the research of Burton and Schuster (1981) provided similar data that allow the hypothesis of female attraction for oviposition in the upper plant-part. Future research must be carried out on the relationship between female trapping and egg presence in the field. The research reported here indicates the need for more evidence on TPW oviposition on different tomato plant stages.

Research on sampling TPW injuries per plant indicated that the percent of the SE corresponding to the mean was 11-31% for 20-25 plants sampled when the population was low (0.2-2.12 injuries per plant) and was 21-29% for 15-20 plants when the population was high (11.05-17.2). By sampling two leaves from the upper and lower canopies I account for 32-34% of the total larval injury per plant. Results indicated a measure of efficiency (RNP) fluctuating between 0.49-1.20 for 50 and 5 plants inspected when the population was small and 0.49-3.18 for 50 and 5 plants when the population was large. Results generally agree with those of Wellik et al. (1979) indicating that larvae are mainly (50-75%) located in the middle-lower plant canopy. Therefore, more samples should be allocated to the middle and lower strata. The average number (n=20) was 2, 3, and 5 samples for upper, middle and lower external canopies, and 0, 5, and 3 from upper, middle and lower internal canopies,

respectively. I recommend more research on the relationship between oviposition and the population index (number of injuries per plant). These data are necessary to establish the prediction of economic injury levels.

Economic injury level studies provided useful data to determine yield losses from high levels of larvae (1-14) per plant. The largest yield reduction was from 12-14 TPW larvae per plant. Since the TPW larva attacks both leaves and fruits, the results suggest that sampling from the lower canopy will be more useful than sampling from the upper canopy. These results disagree with those obtained by Wolfenbarger et al. (1975). Conflicting views about sampling to detect an economic injury level will be fewer if EIL is determined for every stage of tomatoes. I suggest further research to develop economic injury levels for the 4 main stages of development. In this case, it would help to avoid relying on the stages of the plant close to harvest (TR_2), when it is too late to apply control measures.

The role of several factors (parasitoids, field edgerows, rainfall, and horticultural practices) influenced TPW population dynamics in southern Florida. For instance, the effect of natural enemies was an important TPW mortality factor. The role of larval and egg parasitoids increased after the main crop harvest. Levels of TPW larval parasitization fluctuated between 39.3-42.3% during 1980-81. I consider the larval parasitoid *Apanteles* spp. and the egg parasitoid *Trichogramma pretiosum* Riley the most promising biological control agents for TPW in southern Florida. *Apanteles* spp. appeared earlier during the winter season, increasing in density during the months of April-June. *T.*

pretiosum was found to be a TPW egg parasitoid with an intermediate level (33-73%) of parasitism. A conclusion from these data is that studies should be encouraged which focus on the effect of parasitization of larvae and eggs following releases of these beneficials in post-harvested fields. I consider post-harvest agroecosystem management to be a good strategy to assure a low pest density. I recommend further study of TPW parasitoids to find pesticide resistant strains.

Results describing the patterns of colonization of TPW in the field provide answers to the accumulation of TPW in several areas of the field. Data suggested that this microplepidopteran tends to aggregate near field borders, especially near windfalls. These results may encourage further research in dispersal of gelechiids. To understand the dispersion of the different TPW generations, it is important to establish which generation migrates over long distances and which disperses over nearby fields. From a practical standpoint, such knowledge of TPW aggregation can be used for control and monitoring of TPW populations.

Research on effects of abiotic factors such as rainfall indicated reasons for TPW population reduction during 1980-81. The use of artificial rainfall on TPW larvae and pupae demonstrated that when plant foliage was irrigated there was a behavioral change in larval foliar consumption which resulted in 50% reduction of injuries by larvae compared to injuries on soil-irrigated plants. Adult emergence was reduced 93% when high levels of water were applied to the soil. Nevertheless, these experiments require a more elaborate microclimatic study of the pest. I consider it useful to link the similarities of population dynamics of this pest and the potato tuberworm because of their parallel activities related to temperature and rainfall regimes.

The results from evaluation of cultural practices on populations of TPW indicate that post-harvested tomato crops planted earlier (Oct.-Nov., 1980) had a significantly lower mean number of volunteer plants than did the crop planted later (Dec., 1980). Mean numbers of injuries per m^2 were higher in crops planted later (Dec., 1980) than in crops planted earlier (Oct.-Nov., 1980). Despite the complexity and difficulty of proving which cultural practices are most adequate for a sound TPW management program, two different approaches could be taken.

First, practices such as mowing, burning, and discing may eliminate tomatoes as a source of TPW infestation. This implies more supervision from farmers and agricultural agents of post-harvested fields.

Secondly, if habitat management of tomatoes is desired the use of "U-pick," abandoned fields or fields where tomatoes grow voluntarily, should be used as a source for gathering parasites and predators. Natural enemies augmentation could be used to reduce TPW infestations for the next tomato growing season. This may be a large step toward improved management of the TPW.

Several additional studies are needed so that TPW population assessment can be conducted most efficiently. At present, entomologists must continue research on TPW monitoring as well as studying the possible relationship between egg numbers and adults caught by pheromone trapping. In general, a better IPM program in tomatoes will develop when sampling techniques as well as multiple economic injury levels are determined for TPW and other direct pests of tomatoes.

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APPENDIX

EXPLANATORY TABLES FOR CHAPTERS II AND III

Table 48. Tomato pinworm egg frequency distributions determined on tomato plants during 1981.

Planting[a]	Date	N	$\bar{x}$	s^2	k	p	chi^2	p x^2	df	Distribution
4	March 18	18	0.277	0.564	--	--	1.288	0.2564	1	Poisson
					0.234	1.19	1.235	0.2664	1	Negative binomial
	April 1	20	0.050	0.050	--	--	0.0006	1.0000	0	Poisson
	8	20	0.300	0.450	--	--	1.7960	0.1800	1	Poisson
					0.469	0.639	1.1650	0.2800	1	Negative binomial
	16	10	0.200	0.40	--	--	5.6000	0.0179	1	Poisson
					0.097	2.011	1.2900	1.0000	1	Negative binomial
	23	10	0.300	0.233	--	--	0.0860	1.0000	0	Poisson
					1.350	0.222	0.0070	1.0000	1	Positive binomial
	May 1	10	1.300	0.900	--	--	16.2800	0.0002	2	Poisson
					0.084	15.36	1.5500	0.2100	1	Negative binomial
	15	10	1.000	1.470	--	--	1.2800	0.2500	1	Poisson
					1.240	0.30	0.54	0.4600	1	Negative binomial

Table 48--Continued.

5	March 18	20	0.10	0.097	--	--	0.005	1	0	Poisson
					1.90	0.052	0.001	1	-1	Positive binomial
	April 1	20	0.10	0.094	--	--	0.005	1	0	Poisson
					1.9	0.052	0.0012	1	-1	Positive binomial
	8	20	1.30	7.789	--	--	1.7960	0.18	1	Poisson
					0.469	0.639	1.1650	0.28	1	Negative binomial
	16	10	0.20	0.178	--	--	0.0200	1.00	0	Poisson
					1.800	0.111	0.0050	1.00	1	Positive binomial
	23	10	0.40	1.60	--	--	3.7080	0.054	1	Poisson
					0.049	8.147	1.2310	0.267	1	Negative binomial
	May 1	10	0.10	0.10	--	--	0.0020	1.00	0	Poisson
	8	10	0.70	2.45	--	--	1.6600	0.197	1	Poisson
					0.270	2.530	0.9000	0.340	1	Negative binomial
	15	10	0.90	2.32	--	--	0.9600	0.320	1	Poisson
					0.860	1.040	2.2700	0.130	1	Negative binomial

Table 48--Continued.

6	April	1	10	1.9	0.54	--	--	11.69	0.008	3	Poisson
						0.38	4.99	2.65	0.017	4	Negative binomial
		8	10	1.2	2.4	--	--	0.47	0.780	2	Poisson
						1.536	0.78	0.358	0.540	1	Negative binomial
		16	20	0.789	2.509	--	--	4.430	0.035	1	Poisson
						0.29	2.69	3.590	0.162	2	Negative binomial
		23	10	0.300	0.450	--	--	1.796	0.180	1	Poisson
						0.469	0.64	0.375	1.000	0	Negative binomial
	May	1	20	0.500	1.105	--	--	4.190	0.040	1	Poisson
						0.306	1.633	0.905	0.340	1	Negative binomial
		8	10	1.000	2.444	--	--	0.750	0.380	1	Poisson
						0.850	1.170	0.250	0.610	1	Negative binomial
		15	10	0.600	0.933	--	--	0.110	0.730	1	Poisson
						1.408	0.426	1.620	0.203	1	Negative binomial

Table 48--Continued.

7	April	8	10	1.60	4.48	--	--	7.230	0.026	2	Negative binomial
						0.584	2.72	1.218	0.740	3	Poisson
		16	20	0.80	1.221	--	--	1.120	0.280	1	Poisson
						1.262	0.639	1.850	0.170	1	Negative binomial
		23	20	2.05	4.680	--	--	19.43	0.0006	4	Poisson
						1.032	1.987	12.05	0.0300	5	Negative binomial
	May	1	20	1.50	1.421	--	--	0.8546	0.8360	3	Poisson
						28.500	0.052	0.8360	0.6500	2	Negative binomial
		8	20	2.05	7.52	--	--	42.7900	0.0000	4	Poisson
						0.45	4.510	12.550	0.0800	7	Negative binomial
		15	10	0.80	0.178	--	--	2.510	1.0000	0	Poisson

Table 48--Continued.

8	April	8	10	0.111	0.111	--	--	0.064	0.790	1	Poisson
		16	20	1.000	1.895	--	--	8.447	0.014	2	Poisson
						0.981	1.019	3.580	0.163	2	Negative binomial
		23	20	0.900	1.982	--	--	7.310	0.025	2	Poisson
						0.559	1.668	1.280	0.520	2	Negative binomial
	May	1	20	1.400	3.200	--	--	7.27	0.063	3	Poisson
						1.360	1.320	3.460	0.320	3	Negative binomial
		8	20	2.737	8.427	--	--	17.99	0.0002	5	Poisson
						1.503	1.321	15.440	0.0100	6	Negative binomial
		15	20	2.260	14.760	--	--	12.410	0.0100	4	Poisson
						0.650	3.430	4.360	0.6200	6	Negative binomial

[a]Tomato plantings correspond to tomato crops planted: 4) Oct., 1980; 5) Nov., 1980; 6) Dec., 1980; 7) Jan., 1981; and 8) Feb., 1981.

Table 49. Tomato pinworm foliar injury frequency distributions determined on tomato plants during 1980.

Planting[a]	Date	N	$\bar{x}$	s^2	k	p	chi^2	p chi^2	df	Distribution
1	Feb. 8	19	1.211	3.064	--	--	3.77	0.149	2	Poisson
					0.78	1.53	1.79	0.61	3	Negative binomial
	12	18	0.888	2.693	--	--	10.6	0.004	2	Poisson
					0.31	2.833	2.41	0.295	2	Negative binomial
	21	18	2.056	4.291	--	--	9.771	0.04	4	Poisson
					2.176	0.9448	8.481	0.075	4	Negative binomial
	Mar. 14	17	9.882	107.2	--	--	64.69	0	9	Poisson
					0.81	12.11	29.93	0.41	29	Negative binomial
	20	20	7.52	23.76	--	--	18.42	0.010	7	Poisson
					3.39	2.22	13.26	0.42	13	Negative binomial
	Apr. 4	22	23.45	75.59	--	--	54.56	0	15	Poisson
					11.7	2.034	132.8	0	22	Negative binomial
	24	19	13.63	74.36	--	--	24.44	0.0109	11	Poisson
					3.61	3.75	16.52	0.86	24	Negative binomial

Table 49--Continued.

1	May	2	21	21.43	103.8	--	--	71.92	0	14	Poisson
						2.92	7.31	43.24	0.032	28	Negative binomial
		10	19	17.26	109.8	--	--	46.66	0	12	Poisson
						2.66	6.46	23.1	0.811	30	Negative binomial
		20	15	13.00	84.43	--	--	19.52	0.034	10	Poisson
						1.71	7.56	25.13	0.56	27	Negative binomial
	June	1	20	5.2	22.69	--	--	12.73	0.047	6	Poisson
						1.42	3.65	16.04	0.247	13	Negative binomial
2	Feb.	12	20	0.15	0.239	--	--	4.118	0.042	1	Poisson
						0.16	0.89	0.37	1	0	Negative binomial
	Mar.	14	20	8.2	85.12	--	--	46.27	0	8	Poisson
						0.56	14.59	30.35	0.396	29	Negative binomial
		20	19	6.78	64.95	--	--	30.64	6.34×10^{-5}	7	Poisson
						1.06	6.37	17.03	0.58	19	Negative binomial

Table 49--Continued.

2	Apr. 4	20	11.5	44.16	--	--	11.19	0.34	10	Poisson
					5.38	1.37	14.02	0.66	17	Negative binomial
	18	17	10.24	37.57	--	--	28.25	0.0004	8	Poisson
					2.79	3.65	18.53	0.48	19	Negative binomial
	11	20	14.57	46.96	--	--	14.7	0.19	11	Poisson
					7.46	1.95	20.66	0.41	20	Negative binomial
3	Mar. 14	20	0.30	0.274	--	--	3.446	0.063	1	Poisson
					0.05	5.14	0.496	0.48	1	Negative binomial
	20	20	0.1	0.094	--	--	0.114	0.735	1	Poisson
					1.9	0.05	0.05	1.00	0	Positive binomial
	Apr. 11	16	11.0	30.13	--	--	11.52	0.242	9	Poisson
					6.793	1.61	15.84	0.323	14	Negative binomial
	18	25	14.64	42.91	--	--	25.01	0.022	13	Poisson
					8.103	1.307	24.83	0.208	20	Negative binomial

Table 49--Continued.

3	Apr. 25	23	11.17	56.33	--	--	25.45	0.004	10	Poisson
					3.00	3.253	20.22	0.507	21	Negative binomial
	May 10	25	2.04	8.54	--	--	2.04	55.61	4	Poisson
					0.366	5.57	6.41	0.49	7	Negative binomial
	2	18	11.61	22.13	--	--	12.5	0.252	10	Poisson
					13.12	0.38	21.85	0.05	13	Negative binomial

[a] Planting numbers correspond to those tomato crops planted during Nov., Dec., 1979 and Jan., 1980.

Table 50. Tomato pinworm foliar injury frequency distributions determined on tomato plants during 1981.

Planting[a]	Date	N	$\bar{x}$	s^2	k	p	chi^2	p chi^2	df	Distribution
4	Mar. 11	20	0.6	1.095	--	--	5.027	0.02	1	Poisson
					0.44	1.35	1.136	0.286	1	Negative binomial
	18	20	1.5	0.684	--	--	26.47	0	3	Poisson
					0.204	7.32	15.13	0.019	6	Negative binomial
	Apr. 1	8	2.75	1.786	--	--	0.996	0.802	3	Poisson
					3.09	0.38	2.64	0.44	3	Negative binomial
	8	20	1.25	2.09	--	--	3.171	0.20	2	Poisson
					1.64	0.75	1.931	0.37	2	Negative binomial
	16	20	1.77	4.69	--	--	6.100	0.046	2	Poisson
					0.76	2.33	1.083	0.780	3	Negative binomial
	24	20	1.7	0.063	--	--	7.61	0.050	3	Poisson
					1.60	1.60	0.91	0.82	3	Negative binomial
	May 1	19	5.84	17.36	3.14	1.35	28.64	0.009	10	Negative binomial
							28.64	0.0001	7	Poisson

Table 50--Continued.

4	May	8	9	2.22	4.44	--	--	0.44	0.80	2	Poisson
						2.87	0.77	2.63	0.45	3	Negative binomial
		15	10	4.6	18.7	--	--	11.46	0.02	4	Poisson
						2.39	1.98	8.72	0.27	7	Negative binomial
5	Mar.	11	20	0.4	0.35	--	--	0.131	0.716	1	Poisson
						3.8	0.105	0.075	0.780	1	Negative binomial
		18	20	1.05	2.15	--	--	6.54	0.03	2	Poisson
						0.73	1.42	5.96	0.049	2	Negative binomial
	Apr.	8	15	3.6	32.67	--	--	20.4	0.001	5	Poisson
						0.71	5.11	21.51	0.017	10	Negative binomial
		16	20	1.65	2.55	--	--	3.24	0.35	3	Poisson
						4.46	0.36	4.47	0.104	2	Negative binomial
		24	20	1.3	1.8	--	--	1.09	0.57	2	Poisson
						3.67	0.35	0.47	0.68	2	Negative binomial

Table 50--Continued.

5	May	1	19	5.63	10.13	--	--	14.82	0.038	7	Poisson
						6.77	0.33	8.41	0.39	8	Negative binomial
		8	10	2.7	9.56	--	--	8.25	0.04	3	Poisson
						0.85	3.14	4.09	0.53	5	Negative binomial
		15	9	6.77	33.19	--	--	17.34	0.0038	5	Poisson
						1.41	4.778	10.62	0.476	11	Negative binomial
6	Mar.	18	20	0.20	0.48	--	--	2.94	0.290	1	Poisson
						0.09	2.165	1.08	0.298	1	Negative binomial
	Apr.	1	10	0.30	0.45	--	--	1.79	0.180	1	Poisson
						0.46	0.63	0.37	1.00	0	Negative binomial
		8	20	0.45	0.99	--	--	1.86	0.17	1	Poisson
						0.345	1.301	0.015	0.902	1	Negative binomial
		16	15	1.93	1.35	--	--	1.78	0.610	3	Poisson
						6.43	0.30	0.87	0.64	2	Negative binomial

Table 50--Continued.

6	Apr. 24	19	3.78	9.731	--	--	9.35	0.09	5	Poisson
					2.98	1.27	7.37	0.39	7	Negative binomial
	May 1	16	7.81	28.16	--	--	10.56	0.15	7	Poisson
					3.06	2.54	12.29	0.58	14	Negative binomial
	8	24	5.25	16.28	--	--	36.89	0	7	Poisson
					1.67	3.12	19.9	0.09	13	Negative binomial
	15	16	7.56	8.66	--	--	2.53	0.92	7	Poisson
					102.4	0.073	4.76	0.68	7	Negative binomial
7	Apr. 8	20	0.05	0.05	--	--	0.026	0.87	1	Poisson
	16	17	1.23	2.69	--	--	3.75	0.15	2	Poisson
					0.87	1.40	2.37	0.30	2	Negative binomial
	24	20	2.25	4.93	--	--	7.94	0.09	4	Poisson
					2.03	1.104	7.22	0.12	4	Negative binomial
	May 1	17	3.00	8.075	--	--	8.24	0.08	4	Poisson
					1.08	2.76	7.67	0.36	7	Negative binomial
	8	15	4.2	10.46	--	--	14.09	0.014	5	Poisson
					4.83	0.33	9.62	0.21	7	Negative binomial

Table 50--Continued.

7	May 15	15	4.2	10.46	--	--	14.09	0.0149	5	Poisson
					1.76	2.37	13.17	0.10	8	Negative binomial
8	Apr. 24	20	0.55	1.52	--	--	6.59	0.01	1	Poisson
					0.152	3.60	3.06	0.07	1	Negative binomial
	May 1	20	1.7	1.74	--	--	16.13	0.001	3	Poisson
					0.71	2.39	5.92	0.31	5	Negative binomial
	8	20	3.18	5.76	--	--	12.31	0.015	4	Poisson
					4.58	0.69	10.05	0.07	5	Negative binomial
	15	16	3.37	5.98	--	--	3.74	0.44	4	Poisson
					4.76	0.70	8.39	0.135	5	Negative binomial

[a]Planting numbers correspond to those tomato crops planted during: 4) Oct., 1980; 5) Nov., 1980; 6) Dec., 1980; 7) Jan., 1981; and 8) Feb., 1981.

Table 51. TPW egg allocation sample for 6 plant strata. Planting 8, 1981. Age: 38 days. Stage of development TV_2.

	Stratum					
	External			Internal		
Parameter	Upper	Middle	Lower	Upper	Middle	Lower
$\bar{x}$	0.6	0.1	0	0.2	0.4	0
s^2	1.6	0.1	0	0.17	1.6	0
SE	0.4	0.1	0	1.13	0.4	0
SE/$\bar{x}$	0.6	1.0	0	0.65	1.0	0
Sh	1.26	0.31	0	0.41	1.26	0
nh[a]	8.59	2.10	0	2.6	8.59	0
CI[b]	0.6 ± 1.35	0.1 ± 205	--	0.2 ± 1.33	0.4 ± 2.05	—

[a] $nh = \left(\frac{NhSH}{\Sigma NhSh}\right)n$, N=947, n=20

[b] $CI = \bar{x}\pm(SE)t\alpha$

Table 52. TPW egg allocation sample for 6 plant strata. Planting 8, 1981. Age: 46 days. Stage of development TR_1.

Parameter	Stratum: External Upper	External Middle	External Lower	Internal Upper	Internal Middle	Internal Lower
$\bar{x}$	0.4	0.2	0.4	0	0	0
s^2	0.46	0.48	0.98	0	0	0
SE	0.15	0.15	0.22	0	0	0
SE/$\bar{x}$	0.37	0.75	0.55	0	0	0
Sh	0.67	0.69	0.99	0	0	0
nh[a]	5.70	5.75	8.24	0	0	0

[a] $nh = \left(\frac{NhSh}{\Sigma NhSh}\right)n$, N=947, n=20

Table 53. TPW egg allocation sample for 6 plant strata. Planting 7, 1981. Age: 68 days. Stage of development TR_2.

Parameter	Stratum: External Upper	External Middle	External Lower	Internal Upper	Internal Middle	Internal Lower
$\bar{x}$	0.7	0	0.4	0	0.4	0.1
s^2	3.56	0	0.71	0	1.6	0.1
SE	0.59	0	0.26	0	0.4	0.1
SE/$\bar{x}$	0.84	0	0.65	0	1.0	1.00
Sh	1.88	0	0.84	0	1.26	0.31
nh[a]	8.76	0	3.81	0	5.72	1.40
CI[b]	0.7 ± 1.72	0	0.4 ± 1.33	0	0.4 ± 2.05	0.1 ± 2.05

[a] $nh = \left(\frac{NhSh}{\Sigma NhSh}\right)n$, N=947, n=20

[b] $CI = \bar{x} \pm (SE)t\alpha$

Table 54. TPW egg allocation sample for 6 plant strata. Planting 4, 30 Oct. 1980. Age: 77 days. Stage of development TR_2

Parameter	Stratum					
	External			Internal		
	Upper	Middle	Lower	Upper	Middle	Lower
$\bar{x}$	0	0.2	0.15	0	0.05	0.4
S^2	0	0.8	0.23	0	0.05	1.41
SE	0	0.2	0.11	0	0.015	0.26
$SE/\bar{x}$	0	1	0.73	0	0.3	0.65
Sh	0	0.90	0.48	0	0.22	1.18
nh[a]	0	6.47	3.44	0	1.58	8.49
CI[b]	0	0.2 ± 0.41	0.15 ± 0.22	0	0.05 ± 0.03	0.4 ± 0.53

[a] $nh = \left(\frac{NhSh}{\Sigma NhSh}\right)n$, N=947, n=20

[b] $CI = \bar{x} \pm (SE)t\alpha$

Table 55. TPW larval injury sample allocation for 6 plant strata. Planting 6, 1981. Age: 78 days. Stage of development TR_2.

Parameter	Stratum					
	External			Internal		
	Upper	Middle	Lower	Upper	Middle	Lower
$\bar{x}$	0	0	0	0	0.1	0.1
s^2	0	0	0	0	0.20	0.04
SE	0	0	0	0	0.10	0.04
SE/$\bar{x}$	0	0	0	0	1.00	0.44
Sh	0	0	0	0	0.44	0.20
nh[a]	0	0	0	0	12.00	4.00
CI[b]	0	0	0	0		

[a] $nh = \left(\frac{NhSh}{\Sigma NhSh}\right)n$, Nh=947, n=20

[b] $CI = \bar{x} \pm t\alpha(S_{\bar{x}})$

Table 56. TPW larval injury sample allocation for 6 plant strata. Planting 5, 1981. Age: 108 days. Stage of development, TR_2.

Parameter	Stratum					
	External			Internal		
	Upper	Middle	Lower	Upper	Middle	Lower
$\bar{x}$	0.1	0.3	0.3	0	0.4	0.05
s^2	0.2	0.35	0.3	0	0.35	0.05
SE	0.1	0.13	0.12	0	0.13	0.05
SE/$\bar{x}$	1.00	0.44	0.40	0	0.33	1.00
Sh	0.44	0.59	0.54	0	0.59	0.22
nh[a]	4	5	4	0	5	2

[a] $nh = (\frac{NhSh}{\Sigma NhSh})n$, Nh=947, n=20

Table 57. TPW larval injury sample allocation for 6 plant strata. Planting 4, 1981. Age: 120 days. Stage of development, TR_3.

Parameter	Stratum					
	External			Internal		
	Upper	Middle	Lower	Upper	Middle	Lower
$\bar{x}$	0.05	0.20	0.4	0	0.6	0.3
s^2	0.05	0.134	0.87	0	0.78	0.43
SE	0.01	0.08	0.208	0	0.20	0.14
SE/x	0.22	0.40	0.52	0	0.33	0.48
Sh	0.22	0.36	0.93	0	0.88	0.65
Nh[a]	1.25	2.04	5.28	0	5	4

[a] $Nh = (\frac{NhSh}{\Sigma ShNh})n$, Nh=947, n=20

BIOGRAPHICAL SKETCH

Jorge E. Peña was born on April 8, 1948, in Cali, Colombia. He received his high school certificate in 1967 from Colegio Benjamin Herrera in Cali, Colombia. He began his undergraduate studies in 1968 at the Universidad Nacional de Colombia, Facultad de Agronomia, and received the Bachelor of Science degree with a major in agronomy in January 1973.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree Doctor of Philosophy.

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